AD NUMBER
AD370870
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1966. Other requests shall be referred to Air Force Rocket Propulsion Lab., Edwards AFB, CA.
AUTHORITY
31 Dec 1972, GDS, DoD 5200.1-R; AFRPL ltr, 7 May 1973

GENERAL DECLASSIFICATION SCHEDULE

IN ACCORDANCE WITH
DOD 5200.1-R & EXECUTIVE ORDER 11652

THIS DOCUMENT IS:

Subject to General Declassification Schedule of Executive Order 11652-Automatically Downgraded at 2 Years Intervals- DECLASSIFIED ON DECEMBER 31, 1972

BY

Defense Documentation Center
Defense Supply Agency
Cameron Station
Alexandria, Virginia 22314

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.
Separate page printouts MUST be marked accordingly.

CONFIDENTIAL

AFRPL-TR-66-4

(UNCLASSIFIED TITLE)

PROPELLANT HANDBOOK

PAUL J. VON DOEHREN, 1/LT, USAF

JANUARY 1966

AIR FORCE ROCKET PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

CONFIDENTIAL

NOTICES

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Security Classification Notice: The classification of each page represents the highest classification of the contents of the page.

Do not return this copy. When not needed, destroy in accordance with pertinent security regulations.

AFRPL-TR-66-4

(Unclassified Title)

PROPELLANT HANDBOOK

Paul J. von Doehren, 1/Lt, USAF

January 1966

AIR FORCE ROCKET PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

FOREWORD

This report was prepared under task number 314802 by 1/Lt Paul J. von Doehren, Air Force Rocket Propulsion Laboratory (RPCL). The general format of this report is based in part on a compilation (not published as a formal report) by 1/Lt William H. Summers, AFRPL (RPCL) prepared in May 1963. The densities and heats of formation of solid propellant components were abstracted from an unpublished compilation by Curtis C. Selph, AFRPL (RPCL). Acknowledgement of assistance received in the assembly and verification of the data presented in this report is extended to the Liquid Propellant, Solid Propellant, and Chemical and Materials Branches of the Propellant Division, AFRPL.

Classified information has been extracted from documents listed under "References" marked with an asterisk (*).

This technical report has been reviewed and is approved.

GEORGE F. BABITS, Lt Colonel, USAF
Chief, Propellant Division

ELWOOD M. DOUTHETT
Colonel, USAF
Commander, Air Force Rocket Propulsion Laboratory

UNCLASSIFIED ABSTRACT

A compilation of data on both liquid and solid propellants is presented with emphasis on liquids. Physical properties of liquids include: boiling point, freezing point, density, heat of formation, vapor pressure, critical properties, heat of vaporization, viscosity and specific heat. A discussion of the preparation method, toxicity, sensitivity, compatibility and availability of liquid propellants is also given. Property data on solid propellant components consists of densities and heats of formation. The results of theoretical calculations on the performance of both liquids and solids is presented and includes, when available and applicable, the maximum specific impulse, characteristic exhaust velocity, chamber temperature, mixture ratio, bulk density, maximum density impulse and mixture ratio, vacuum specific impulse and area ratio.

TABLE OF CONTENTS

SECTION VII

Theoretical Performance Data for Oxidizers with Various Fuels

I. INTRODUCTION

INTRODUCTION

This handbook is intended as a source of general information concerning rocket propellant properties and theoretical performance. The inclusion (or exclusion) of a propellant or propellant combination does not necessarily reflect the current Air Force interest in propellant systems. Some general comments concerning the treatment and compilation of data for this handbook are outlined in the following paragraphs.

Liquid Propellant Properties

The sections on liquid propellant properties give physical property, preparation, toxicity, sensitivity, compatibility and availability data for rocket propellants. Additional information in these areas is available in many cases by referring to the original source. When several different values of a physical property were found, in general, either the one appearing most frequently or the latest value was selected. If a value is in question or its precision critical then it would be advisable to refer to the original reference.

Propellant property information will be available after June 1966 from Contract AF 04(611)-10546, "Engineering Property Data on Rocket Propellants". The handbook published under this contract, when available, should be consulted for current property information.

Liquid Propellant Theoretical Performance

The latest JANAF propellant data was used in calculating theoretical propellant performance on the AFRPL (IBM 7040) computer program. Curves of specific impulse, chamber temperature, characteristic exhaust velocity, etc. vs percent oxidizer were plotted by hand and the appropriate values extracted from these curves. The performance values are intended to provide a rough means of determining the relative merit of propellant combinations.

No allowance was made for the gelling agent or emulsion external phase when calculating the theoretical performance of metal suspension systems. The data for these systems can therefore be considered an upper limit of performance since the additives to produce gels or emulsions have a relatively low performance level. The amount of degradation in performance will vary according to the amount and type of gelling agent or external phase used.

Solid Propellant Properties

This section gives densities and heats of formation for various fuels, oxidizers, binders and additives. This information was originally assembled as a data source for in-house theoretical performance calculations.

Solid Propellant Theoretical Performance

The theoretical performance data for selected solid propellant compositions are listed according to the fuel and oxidizer used. The information was assembled from AFRPL calculations and available literature and is intended to give an overall view of the theoretical performance available from selected solid propellant compositions.

II. LIQUIL PROPELLANT PROPERTIES

(Fuels)

HYDRAZINE

Formula: N_2H_4

Physical Properties:

Boiling Point:	113°C	(1)
Freezing Point:	1.4°C	(1)
Density:	1.008 g/cc @ 20°C	(1)
Heat of Formation:	+12.05 Kcal/mole @ 298.15°K	(2)
Vapor Pressure:	0.204 psia @ 20°C 2.806 psia @ 70°C	(1)
Critical Temperature:	380°C	(1)
Critical Pressure:	145 atm	(1)
Heat of Vaporization:	10.7 Kcal/mole @ 25.0°C	(1)
Viscosity:	0.9736 cp @ 20°C	(1)
Specific Heat:	0.738 cal/gm°C @ 25°C	(1)

Preparation: Hydrazine is manufactured by the Raschig process, which involves the oxidation of ammonia to chloramine, either indirectly with aqueous sodium hypochlorite or directly with chlorine, and subsequent reaction of chloramine with excess ammonia. (9)

Toxicity: If spilled on the skin or in the eyes, liquid hydrazine can cause severe local damage or burns and can cause dermatitis. In addition, it can penetrate skin to cause systemic effects similar to those produced when the compound is swallowed or inhaled. If inhaled, the vapor causes local and systemic effects. Repeated exposure may cause toxic damage to the liver and kidney, as well as anemia. The threshold limit is 1 ppm (1.3 mg/cu m). (7)

Sensitivity: Hydrazine is a stable liquid under the extremes of heat and cold expected in long-term storage. It will freeze, but contracts, so no vessel damage results. Freezing does not affect the chemical properties of hydrazine. Thermal decomposition begins at about 320°F, but if hydrazine is permitted to remain in contact with catalysts such as copper, molybdenum or iron oxide, decomposition may occur at room temperature. Liquid hydrazine is stable to shock. Hydrazine vapor can be exploded by a spark or flame if it is within the flammable limits. (7)

Compatibility: The following metals may be used with hydrazine: stainless steel (303, 304, 316, service limited to 160°F, 321 and 347), nickel, aluminum (3003, 5052, 5154, 1060 and 6061). Nonmetals include Teflon, high-density polyethylene and unplasticized Kel-F. Thus far, a completely satisfactory lubricant has not been developed. The Quigley Company's "Q-Seal" is being used with fair results. (7)

Availability: Anhydrous hydrazine is readily available. Present cost: $.72 per pound.

Remarks: For additional information consult references (1) and (12).

Military Specification, Mil-P-26536, Propellant, Hydrazine

MONOMETHYL HYDRAZINE (MMH)

Formula: $(CH_3)HNNH_2$

Physical Properties:

Boiling Point:	87.5°C	(1)
Freezing Point:	-52.4°C	(1)
Density:	0.8743 @ 25°C	(1)
Heat of Formation:	12.7 Kcal/mole	(1)
Vapor Pressure:	49.63 mm Hg @ 25°C	(1)
	171 mm Hg @ 50°C	(1)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	9648 cal/mole @ 25°C	(1)
Viscosity:	0.893 centistokes	(1)
Specific Heat:	32.25 cal/mole°K @ 25°C	(1)

Preparation: MMH may be produced by a modified Raschig process; methylamine is substituted for ammonia in the reactor with chloramine (see hydrazine). (9)

Toxicity: Liquid MMH in contact with skin or eyes can cause local damage resembling burns; in addition, it can penetrate skin to cause systemic effects. Inhalation of the vapor causes from slight to severe irritation of the respiratory passages, as well as systemic effects. Evidence on the effects of chronic toxicity is lacking. No threshold limit value for MMH has been recommended; consideration of data on its acute toxicity and analogy with UDMH and hydrazine suggest that the proper value should be below 0.5 ppm. (7)

Sensitivity: MMH is a stable liquid under the extremes of heat and cold expected in long-term storage. It will freeze, but because it contracts on freezing there is no damage to storage vessels. It is stable up to its atmospheric boiling point if kept from contact with oxygen. Catalysts such as rust, copper or copper alloys can cause it to decompose and finally to ignite. MMH is stable to friction or impact. Vapors of MMH within flammable limits can be exploded by a spark or flame. (7)

Compatibility: The acceptability of materials in contact with MMH depends upon the specific application for which they are intended. The requirements for long-term storage differ considerably from those pertaining to a once-used piece of equipment. If the properties (or other aspects) of a material indicate the desirability of its use, it would be well to evaluate this material with MMH under the conditions expected during operation before removing it from consideration. Because of MMH's solvent properties, no completely suitable lubricant has been found. (7)

Availability: Readily available. Present cost: $2.47 bulk pound. Projected cost for larger scale production is $0.60 to $1.25/lb. (9)

Military Specification, Mil-P-27404, Propellant, Monomethyl Hydrazine

UNSYMMETRICAL DIMETHYL HYDRAZINE (UDMH)

Formula: $(CH_3)_2NNH_2$

Physical Properties:

Boiling Point:	63°C	(1)
Freezing Point:	-57.21°C	(1)
Density:	0.7861 @ 25°C	(1)
Heat of Formation:	+11.9 Kcal/mole @ 298.15°K	(2)
Vapor Pressure:	2.3668 @ 25°C	(1)
Critical Temperature:	249°C	(1)
Critical Pressure:	60 atm	(1)
Heat of Vaporization:	8.366 Kcal/mole @ 25°C	(1)
Viscosity:	0.509 cp @ 25°C	(1)
Specific Heat:	0.6526 cal/gm°C @ 25°C	(1)

Preparation: UDMH can be produced commercially by nitrosation of dimethylamine, to N-nitrosodimethylamine, followed by reduction of the intermediate to UDMH and subsequent purification. UDMH can be prepared, also, by a modification of the Raschig process, in which the chloramine intermediate is reacted with dimethylamine rather than with ammonia. (9)

Toxicity: UDMH is mildly irritating to skin and eyes and can penetrate skin to cause systemic toxicity, but it is not as dangerous in this regard as hydrazine. The vapor causes eye and respiratory irritation as well as systemic effects. The results of repeated exposure may be chronic poisoning, characterized by anemia. The threshold limit of UDMH is 0.5 ppm. (7)

Sensitivity: UDMH is not shock sensitive. It shows good thermal stability, even up to its critical temperature, 480°F. The spontaneous decomposition temperature of UDMH in an atmosphere of nitrogen or helium has been determined to be 740°F to 750°F at 1 atmosphere, but decomposition does not become explosive up to at least 1112°F. (7)

Compatibility: UDMH is compatible with most common metals and may be handled in containers made of those materials under a wide variety of conditions. There is no known limitation on use of UDMH with nickel, Monel or types 303, 304, 316, 321 and 347 stainless steel. It has been noted that aluminum is attacked to some extent by dilute aqueous solutions of UDMH. UDMH typically contains about 0.1% water. The use of copper and high copper alloys is prohibited in UDMH transfer and storage equipment. In view of the variable nature of the service in which nonmetals may be used, it is undesirable to be specific regarding their performance. Apiezon L and Reddy Lube 200, the best lubricants currently known, are satisfactory for many applications. (7)

Availability: Readily available at $.56 a bulk pound.

Military Specification, Mil-P-25604, Propellant, una Dimethylhydrazine

50/50 UDMH/N_2O_4 (AEROZINE 50)

Composition: 51% N_2H_4
49% $(CH_3)_2NNH_2$

Physical Properties:

Boiling Point:	70.1°C	(10)
Freezing Point:	17.3°C	(10)
Density:	0.899 g/cc @ 25°C	(10)
Heat of Formation:*	12.251 Kcal/mole @ 25°C (calc)	(10)
Vapor Pressure:	142.1 mm Hg @ 25°C	(10)
Critical Temperature:	334°C (calc)	(10)
Critical Pressure:	115.4 atm (calc)	(10)
Heat of Vaporization:	236.7 cal/gm (calc)	(10)
Viscosity:	0.91 centistokes @ 25°C	(10)
Specific Heat	0.694 cal/gm°C	(10)

Preparation: 50/50 is a mixture of commercial concentrated hydrazine and commercial UDMH in approximately equal portions by weight. Typical composition: N_2H_4 51.0%, UDMH 48.2%, H_2O 0.5% and other impurities 0.3%. (10)

Toxicity: UDMH constitutes 90% of the vapor. It may be absorbed through the intact skin, by inhalation of fumes and by ingestion. 50/50 can cause irritation of the mucous membranes of the eyes, respiratory passages, lungs and gastrointestinal tract. Immediate symptoms of inhalation are chest pain, coughing, wheezing, nausea and vomiting. If large amounts have been inhaled, pulmonary edema may occur. Allowable concentration, 0.5 ppm. (11)

Sensitivity: Both constituents react with air so that 50/50 should be kept under a nitrogen blanket. (See UDMH and Hydrazine) (10)

Compatibility: Compatible with: stainless steel, aluminum, titanium and nickel alloys, Diamine Nylons, Teflon, certain butyl-rubber compounds, graphite and some silicone-base greases. Alloys of copper may be used only in specific applications upon advice of a metallurgist. Alloys of magnesium and zinc are not recommended. (10)

Availability: Readily available at $.66/lb.

Remarks: For further information see references (10) and (11).

*Based on the composite formula $C_{0.678}H_{5.356}N_{2.0}$

Military Specification, Mil-P-27402, Propellant, Hydrazine - uns-Dimethylhydrazine (50% N_2H_4 - 50% UDMH)

RP-1

Formula: $CH_{1.9532}$

Physical Properties:

Boiling Point:	177 to 274°C	(9)
Freezing Point:	-40°C (maximum)	(9)
Density:	0.801 to 0.815 g/cc @ 20°C (Mil Spec)	
Heat of Formation:	-5.76 Kcal/mole	(3)
Vapor Pressure:	0.36 psia @ 66°C	(1)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	16.5 centistokes @ -34.4°C (Mil Spec)	
Specific Heat:	---	

Preparation: RP-1 is a straight-run kerosene fraction, which is subjected to further treatment, i.e. acid washing, sulfur dioxide extraction. Unsaturated substances which polymerize in storage are removed, as are sulfur-containing hydrocarbons. The kerosene must be obtained from crudes with a high naphthene content. (9)

Toxicity: RP-1 produces moderate skin irritation and after more than momentary contact can cause scaling and fissuring of the skin. The main danger comes from accidental swallowing; while not especially toxic by this route, gasping while swallowing or aspiration from improperly induced vomiting can introduce the liquid into the lungs, and pulmonary edema may ensue.

Sensitivity: RP-1 is chemically stable and insensitive to shock. It shows good thermal stability over a wide range of ambient storage temperatures, but exposure to high temperatures accelerates the formation of gum and sediment.

Compatibility: Steel should be used with RP-1. Copper alloys (with brass, bronze or beryllium) should not be used where they will be continually in contact with the fuel, as they promote gum formation. The following non-metals may be used: vinyls, Teflon, Kel-F, polyethylene, polyamides, neoprene, Buna N and asbestos, cork and paper gasket materials designed for this service. Graphite-base, molybdenum-disulfide and some silicone and fluorocarbon lubricants may be used.

Availability: RP-1 is readily available at $.15 a pound.

Military Specification, Mil-P-25576, Rocket Fuel RP-1

HYDROGEN

Formula: H_2

Physical Properties:

Boiling Point:	20.39°K	(1)
Freezing Point:	-259.14°C	(1)
Density:	0.0710 g/cc @ 20.39°K	(1)
Heat of Formation:	-1.887 Kcal/mole @ 20.4°K	(1)
Vapor Pressure:	---	
Critical Temperature:	33.26°K	(1)
Critical Pressure:	12.8 atm	(1)
Heat of Vaporization:	0.2193 K cal/mole @ 20.38°C	(1)
Viscosity:	140.9 x 10^{-6} poise @ 20.39°K	(1)
Specific Heat	1.45 cal/gm @ -253°C	(1)

Preparation: Hydrogen is produced from by-product hydrogen from petroleum refining and the partial oxidation of fuel oil. The gaseous hydrogen is purified to 99.999+ per cent, and then liquified in the presence of paramagnetic metallic oxides. It is composed of 99.79 per cent parahydrogen. (9)

Toxicity: Hydrogen is not toxic in the usual sense. Serious burns can result when skin or other tissues come into contact with the liquid or with pipes and valves containing the liquid because of its temperature. The gas can exclude oxygen and cause asphyxiation. Cold hydrogen vapors can also "burn" the skin. (7)

Sensitivity: Liquid hydrogen is chemically stable. Because of its low boiling point, it is physically stable only when stored under suitable conditions. (7)

Compatibility: The ability of materials to retain satisfactory properties and withstand stresses caused by large temperature changes is of prime importance. Suitable metals include: stainless steel (300 and other austenitic series), copper, bronze, brass, Monel, aluminum and Everdur. Non-metals include: Dacron, Teflon, Kel-F, Asbestos impregnated with Teflon, Mylar films and Nylon. Lubricants are generally not practical in the presence of liquid hydrogen, for they solidify and become brittle at the liquid's temperature. Vacuum grease is satisfactory as a sealant with "O" rings. (7)

Availability: Readily available, present cost is $.85 per pound. Larger scale production is expected to reduce the cost to $0.50 per pound. (9)

Military Specification, Mil-P-27201, Propellant, Hydrogen

AMMONIA

Formula: NH_3

Physical Properties:

Boiling Point:	-33.4°C	(1)
Freezing Point:	-77.7°C	(1)
Density:	0.6920 g/cc @ -33.4°C	(1)
Heat of Formation:	-17.14 Kcal/mole	(1)
Vapor Pressure:	---	
Critical Temperature:	132.4°C	(1)
Critical Pressure:	111.3 atm	(1)
Heat of Vaporization:	4805 cal/mole @ 25°C	(1)
Viscosity:	0.266 cp @ -33.5°C	(1)
Specific Heat:	18.12 cal/mole°C @ -33.1°C	(1)

Preparation: Ammonia is produced by the Haber-Bosch process, in which the elements, nitrogen and hydrogen, are united at a temperature of 500 to 600°C and a pressure of approximately 200 atm in the presence of a promoted iron catalyst. (9)

Toxicity: Liquid ammonia, because of its low temperature and caustic properties, can cause damage to the skin and eyes. The vapor is irritating to the skin, eyes and respiratory tract. The threshold limit value is 50 ppm. The odor is usually detectable below the limit. Inhalation of concentrations around 2500 ppm are hazardous to life in one-half hour. (7)

Sensitivity: Ammonia is very stable and is not shock sensitive. It is thermally stable at temperatures as high as 480°C, above which dissociation to nitrogen and hydrogen begins. (7)

Compatibility: Anhydrous ammonia (liquid) and ammonia vapor may be used with nickel and stainless steel (300 and 400 series) at all temperatures and with steel at ambient temperatures. Teflon, Kel-F and pure asbestos may be used. Fluorolubes or the perfluorocarbons may be used as lubricants. Other materials which have been tested and approved for ammonia service may be used. (7)

Availability: Anhydrous ammonia is readily available at $.05 a pound.

Military Specification, Mil-P-27406 (Not Approved)

PENTABORANE

Formula: B_5H_9

Physical Properties:

Boiling Point:	-46.6°C	(16)
Freezing Point:	60.0°C	(16)
Density:	0.618 g/cc @ 25°C	(16)
Heat of Formation:	+7.74 Kcal/mole @ 298.15°K	(2)
Vapor Pressure:	64.7 mm Hg @ 0.0°C	(16)
	4.0 psia @ 25°C	(16)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	7.28 Kcal/mole @ 25°C	(16)
Viscosity:	0.499 centistokes @ 25°C	(16)
Specific Heat	36.2 cal/mole°C @ 25°C	(16)

Preparation: Pentaborane is produced by the pyrolysis of diborane; the conversion is not a clean cut reaction. The resulting products are dependent upon the pyrolysis temperature. At 180°C the predominant products are B_5H_9 and $B_{10}H_{14}$. (9)

Toxicity: Inhalation is the most common means by which pentaborane enters the body. In most cases of poisoning, there will be signs and symptoms of the involvement of the central and possibly the peripheral nervous systems. The onset of symptoms may be delayed several hours. Exposure may cause abnormalities for several days despite outward appearances and recovery may not be complete for several weeks. The threshold limit is 0.005 ppm (0.01 mg/cu m). (7)

Sensitivity: In the absence of air or contaminants, pentaborane is stable at room temperature. It decomposes at 302°F, but not explosively. Small amounts of oxygen or moisture will cause solid deposits to form in pentaborane. Metal oxides also affect its stability. (7) Pentaborane, by itself, is insensitive to shock, however, it may form shock sensitive compounds with most chlorinated organic compounds having more than one chlorine per carbon or containing carbonyl groups. (16)

Compatibility: The following metals are approved for use: aluminum (5052-S, 6061-T6, 7075-T6, 2024-T3, 3003-H14, 356-T6) (These alloys may be anodized), stainless steel (18-8 series), low carbon steels, K-Monel, Monel M-8330-B, nickel, Nichrome "V" Magnesium, Fed-QQ-M-44A and Fed-QQ-M-56-A263, titanium C-130AM and C-110AM, copper, brass and Hastelloy. The following nonmetals may be used: Kel-F, Kel-F-5500, Teflon, fluorosilicone rubbers, Fluoroflex "T", glass, Viton "A" and "B", dry asbestos, Garlock 230 and carbon. The following lubricants may be used: Graphitar Nr. 39, Hercules No. 571 Kaobestos, Rockwell Nordstorm Lube No. 921 and Gulf Harmony Oil Nos. 44 and 69. Pentaborane forms shock sensitive mixtures with some solvents. (7)

Availability: Produced by Callery Chemical Co. No longer in production. A limited quantity is in storage at the present time.

Remarks: For further information see references (15) and (16).

Military Specification, Mil-P-27403, Propellant, Pentaborane

DIBORANE

Formula: B_2H_6

Physical Properties:

Boiling Point:	-92.5°C	(1)
Freezing Point:	-165.5°C	(1)
Density:	0.437 g/cc @ -92.6°C	(1)
Heat of Formation:	+2.93 Kcal/mole @ -92.5°C	(4)
Vapor Pressure:	---	
Critical Temperature:	16.7°C	(1)
Critical Pressure:	39.5 atm	(1)
Heat of Vaporization	3.413 Kcal/mole @ -92.53°C	(1)
Viscosity:	1.33 millipoise @ -92.5°C	(4)
Specific Heat:	18.5 cal/mole°K @ -92.5°C	(1)

Preparation: Diborane may be made by a number of processes. In general, the methods involve the decomposition of a metal borohydride, the reduction of a metal borofluoride, or the reduction of a boron halide. Diborane may be produced by the reaction of an alkali metal borohydride ($LiBH_4$) with boron trichloride in an inert solvent. The diborane is purified by selective liquification at a low temperature. (9)

Toxicity: Diborane is a highly toxic irritant to the pulmonary system. It is not known whether severe or repeated exposure would result in permanent injury. Diborane may impair the sense of smell and therefore odor is not to be relied upon as a means of detection. Cough and tightness in the chest follow immediately upon exposure and serve as a warning. Threshold limit is 0.1 ppm for 8 hr daily exposure. Hazardous exposure occurs only by inhalation. (15)

Sensitivity: Diborane is a very flammable gas with wide explosive limits and high flame and detonation speeds. Although diborane itself is not spontaneously flammable in air at room temperature, it may be ignited by a static spark, heat of reaction, heat of absorption or the spontaneous ignition of one of its thermal decomposition products. (4)

Compatibility: The following materials of construction were found to be suitable for use with gaseous diborane on exposure at ambient temperatures: Teflon, Kel-F, Saran, brass, lead, nickel, K Monel, low carbon steel, stainless steel 18-8, asbestos-graphite-copper valve packing and Vaseline-paraffin-graphite lubricant. (4)

Availability: Limited availability at the present time.

Military Specification, None

MHF-1

Composition: 43.3% MMH
23.5% N_2H_4
34.1% Hydrazinium nitrate ($N_2H_5NO_3$)
$(C_{0.474}H_{5.119}O_{0.5205}N_{2.2725})$

Physical Properties:		
Boiling Point:	107.3°C	(21)
Freezing Point:	-54°C	(21)
Density:	1.084 g/cc @ 25°C	(21)
Heat of Formation:*	0.04 Kcal/mole (calc)	(3)
Vapor Pressure:	0.50 psia @ 25°C	(21)
	5.4 psia @ 71°C	(21)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	3.6 centistokes @ 25°C	(21)
Specific Heat:	0.62 Btu/lb°F @ 25°C	(21)

MHF-3

Composition: 86% MMH
14% N_2H_4
$(C_{0.81}H_{5.62}N_{2.0})$

Physical Properties:		
Boiling Point:	92°C (calc)	(21)
Freezing Point:	-60°C	(21)
Density:	0.90 g/cc @ 15.6°C (calc)	(21)
Heat of Formation:*	12.58 Kcal/mole (calc)	(3)
Vapor Pressure:	0.5 psia @ 15.6°C (calc)	(21)
	9.9 psia @ 79.8°C	(21)
Critical Temperature:	264°C	(21)
Critical Pressure:	93.5 atm	(21)
Heat of Vaporization:	---	
Viscosity:	1.3 centistokes @ 15.6°C	(21)
Specific Heat:	0.71 Btu/lb°F @ 15.6°C	(21)

MHF-5

Composition: 55% MMH
26% N_2H_4
19% $N_2H_5NO_3$
$(C_{0.541}H_{5.173}O_{0.273}N_{2.091})$

Physical Properties:		
Boiling Point:	80°C	(21)
Freezing Point:	-57°C	(21)
Density:	1.011 g/cc @ 25°C	(21)
Heat of Formation:*	5.936 Kcal/mole (calc)	(3)

*Based on composite formula

Vapor Pressure:	0.77 psia @ 25°C	(21)
	7.7 psia @ 80°C	(21)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	1.9 centistokes @ 25°C	(21)
Specific Heat:	0.66 Btu/lb°F @ 25°C	(21)

Preparation: The MHF fuels are prepared by mixing together the individual components.

Toxicity: For toxicity information refer to the section on hydrazine and monomethyl hydrazine. The toxicity limits are estimated to be the same magnitude as the major constituents 0.5 to 1.0 ppm. (21)

Sensitivity: The mixed hydrazine fuels are safe to handle. They have been found to be insensitive to shock by three different tests: JANAF drop weight test, the Frauzl Block test and the JANAF card gap test. MHF-3 was shown to be the safest of the three blends. In addition, MHF-1 has been found not shock sensitive per the Icc explosive test. MHF can form flammable and explosive mixtures in air.

Compatibility: MHF is relatively noncorrosive for most stainless steel and aluminum alloys. The compatibility of MHF-3 was established with aluminum (2014, 2024, 7178), the high-strength steels (AFC-77, AM301, cryogenic stretch-formed) and AM357. The long-term compatibility of aluminum alloys with MHF fuels is excellent. The Hastelloys, Monel, 40E aluminum, magnesium, zinc, lead, copper and its alloys and iron are not recommended for use with MHF. The following non-metals are also compatible with MHF: braided asbestos impregnated with Teflon, Teflon and high-density polyethylene, Garlock 735, Mylar film and unplasticized Kel-F. MHF decomposition in the presence of metals is observed to occur in two phases: a steep initial rate as the surface is passivated and then leveling off to a relatively lower rate characteristic of the material.

Availability: Availability only limited by the availability of the ingredients.

Military Specification, None

MAF-1

Composition: 40.5% UDMH
50.5% Diethylenetriamine (DETA)
9.0% Acetonitrile (CH_3CN) (22)

Physical Properties:

Boiling Point:	77°C	(22)
Freezing Point:	very viscous at -70°C	
	sets to glass below -100°C	(22)
Density:	0.869 g/cc @ 25°C	(22)
Heat of Formation:*	7.1 Kcal/mole	(22)
Vapor Pressure:	104 mm Hg @ 25°C	(22)
	190 mm Hg @ 40.2°C	(22)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	0.58 cp @ 71°C	(22)
Specific Heat	0.67 Btu/lb°F @ 25°C	(22)

Preparation: Prepared by mixing the individual components.

Toxicity: A rough estimate of the toxicity limits can be gained from its components. DETA has a concentration limit of 20 ppm and UDMH has a limit of 0.5 ppm. (22)

Remarks: Additional information on this propellant is not available at this time.

*Based on the composite formula $C_{2.708}H_{8.822}N_{2.196}$

Military Specification, Mil-P-23741, Propellant, Mixed Amine Fuel

HYBALINE A4

Formula: $C_2NH_{19}AlB_3$

Physical Properties:

Boiling Point:	greater than 220°C	(6)
Freezing Point:	-7.5°C (Melting Pt. +4.5°C)	(6)
Density:	0.759 gm/cc	(6)
Heat of Formation:	-16.5 Kcal/mole	(6)
Vapor Pressure:	2 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	9.2 cp @ 20°C	(6)
Specific Heat:	---	

Preparation: $Al(BH_4)_3 + (CH_3)_2NH \longrightarrow (CH_3)_2NH \cdot Al(BH_4)_3$
Reaction carried out in inert solvent such as n-hexane or benzene

Toxicity: Hybaline appears less toxic by inhalation than hydrazine, UDMH, Aerozine 50, pentaborane, diborane, IRFNA and nitrogen tetroxide. Although skin contact with the Hybalines must be avoided, protection requirements are no more stringent than for several of the other high energy fuels. No limits have been established for maximum allowable vapor concentrations. Personnel should not remain in confined areas where significant quantities of Hybaline have been spilled without air supplied respiratory equipment. The decomposition products of Hybaline may contain boron hydrides such as diborane. Skin and eye contact with Hybalines will cause burns and must be avoided. (6)

Sensitivity: Hybaline A is not considered shock sensitive. Negative results have been obtained for No. 6 blasting cap tests and the Olin Mathieson drop weight tester. Hybaline A oxidizes slowly in dry air. However, it readily ignites in moist air or water. Hybaline A should not be exposed directly to the air, but should be handled in an inert atmosphere such as nitrogen or helium. Oxygenated compounds can also ignite Hybaline A. Overheating can result in the release of hydrogen from Hybaline A. All storage tanks should be provided with pressure gauges and over-pressure relief devices to prevent excessive build-up in pressure due to external heating. (6)

Compatibility: Static compatibility testing of Hybaline A-5 has shown the following materials to be compatible: steel, 304 stainless steel, copper, nickel, Monel, tinned iron, galvanized iron, aluminum (2219-T89, 2014-T6), Titanium 110, Teflon, Viton A, Neoprene 7794 and red rubber. Compatibility with A-4 should be the same.

Availability: Nine hundred pounds of A-4 have been produced by Union Carbide Corp (disregarding A-4 used in preparation of A-5). The production facility is on standby at the present time. Approximately three months would be required to reach full production capacity. Cost: $76 a pound.

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

HYBALINE A5

Formula: $C_{1.47}NH_{17.94}AlB_3$

Physical Properties:

Boiling Point:	263°C	(6)
Freezing Point:	sets to glass below -40°C	(6)
Melting Point:	4°C	(6)
Density:	0.736 gm/cc @ 20°C	(6)
Heat of Formation:	-16.5 Kcal/mole	(6)
Vapor Pressure:	3 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization	4990 cal/mole	(6)
Viscosity:	6.78 cp @ 20°C	(6)
Specific Heat:	0.621 cal/gm @ 20°C	(6)

Preparation: $2Al(BH_4)_3 + CH_3NH_2 + (CH_3)_2NH \longrightarrow$

$CH_3NH_2 \cdot Al(BH_4)_3 + (CH_3)_2NH \cdot Al(BH_4)_3$

(53 wt %) (47 wt %)

Reaction carried out in inert solvent such as n-hexane or benzene.

Toxicity: Hybaline appears less toxic by inhalation than hydrazine, UDMH, Aerozine 50, pentaborane, diborane, IRFNA and nitrogen tetroxide. Although skin contact with the Hybalines must be avoided, protection requirements are no more stringent than for several of the other high energy fuels. No limits have been established for maximum allowable vapor concentrations. Personnel should not remain in confined areas where significant quantities of Hybaline have been spilled without air supplied respiratory equipment. The decomposition products of Hybaline may contain boron hydrides such as diborane. Skin and eye contact with Hybalines will cause burns and must be avoided. (6)

Sensitivity: Hybaline A is not considered shock sensitive. Negative results have been obtained from No. 6 blasting cap tests and the Olin Mathieson drop weight tester. Hybaline A oxidizes slowly in dry air. However, it readily ignites in moist air or water. Hybaline A should not be exposed directly to the air, but should be handled in an inert atmosphere such as nitrogen or helium. Oxygenated compounds can also ignite Hybaline A. Overheating can result in the release of hydrogen from Hybaline A. All storage tanks should be provided with pressure gauges and over-pressure relief devices to prevent excessive build-up in pressure due to external heating. (6)

Compatibility: Static compatibility testing of Hybaline A5 has shown the following materials to be compatible: steel, 304 stainless steel, copper, nickel, Monel, tinned iron, galvanized iron, aluminum (2219-T89 and 2014-T6), titanium 110, Teflon, Viton A, Neoprene 7794 and red rubber.

Availability: A total of 11,716 pounds of Hybaline A5 were produced by Union Carbide Corporation under Contract AF 04(611)-8164. Approximately 1/3 of this material remains in storage at the present time. The production facility is now on standby. Approximately three months would be required to reach full production capacity. Cost: $76 per pound. The projected cost of Hybaline A5 in large production quantities has been established at $20 per pound for quantities up to 300,000 lbs/yr and $18 per pound for a production rate of 600,000 lbs/yr.

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

HYBALINE B3

Formula: $BeB_2CH_{13}N$

Physical Properties:

Boiling Point:	greater than 270°C	(6)
Freezing Point:	between -80°C & -23°C	(6)
Density:	0.667 gm/cc	(6)
Heat of Formation:	-19.5 Kcal/mole	(6)
Vapor Pressure:	1.5 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	3.4 cp @ 20°C	(6)
Specific Heat:	0.625 cal/gm @ 20°C	(6)

Preparation: $Be(BH_4)_2 \cdot (C_2H_5)_2O + CH_3NH_2 \longrightarrow CH_3NH_2 \cdot Be(BH_4)_2$
Reaction carried out in petroleum ether or diethyl ether.

Toxicity: The main consideration in the use of Hybaline B3 is the beryllium toxicity. The manifestations of beryllium poisoning have been divided into three classes: acute berylliosis, chronic berylliosis and dermatitis. The more serious effects are due entirely to inhalation of beryllium or its compounds. The onset of symptoms accompanying chronic berylliosis may be delayed as much as 10 years or longer after the last exposure. (8) In addition to beryllium toxicity, skin and eye contact with B3 will cause burns. (6)

Sensitivity: The same considerations apply to B3 as apply to Hybaline A (See Hybaline A5). (6)

Compatibility: The compatibility should resemble the Hybaline A series (See Hybaline A5). (6)

Availability: A total of 199 pounds of B3 were produced by Union Carbide Corp under Contract AF 04(611)-8164. The production facility is on standby at the present time. Cost: $300 a pound. A limited quantity is available at the present time. (8)

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

GELS AND EMULSIONS

The performance of many propellant systems can be improved by the addition of the light metals or their hydrides. Gel and emulsion techniques are used to provide a uniform distribution of the metal or hydride in the fuel. (29)

Gels:

A gel is obtained by either chemically or mechanically immobilizing the liquid and trapping the metal or hydride dispersed throughout the liquid. The gel should have a sufficiently high yield stress to support the suspended solid and prevent it from settling out as a result of normal handling and storage. Ideally the gel acts like a solid during static conditions yet behaves like a liquid under flow conditions (low apparent viscosity). (28) (29)

Gelling agents may be divided into roughly two categories: particulate and swellable agents. Particulate gelling agents depend on the ability of the particles to bond to one another by attractive forms in order to form the necessary suspension network. Swellable agents are materials (e.g. organic polymers and natural gums) which appear to depend on the physicochemical interaction between the gelling agent and the carrier fluid.

Physical Properties of Alumizine - 43G:

Boiling Point:	NA, est. approx. 114°C	(29)
Freezing Point:	0°C	(29)
Density:	1.366-1.380 g/cc @ 77°F	(29)
Vapor Pressure:	0.27 psi @ 25°C	(29)
	1.8 psi @ 60°C	(29)
Yield Stress:	1400 to 2200 dyne/sq cm @ 25°C	(29)
Apparent Viscosity @ 25°C:		
(Ferranti-Shirley Viscometer)	29 to 41 cp ($17{,}300\ sec^{-1}$)	(29)
	400 to 600 cp ($300\ sec^{-1}$)	(29)
	700 to 1300 cp ($100\ sec^{-1}$)	(29)
Apparent Viscosity: (Brookfield, Spindle No. 4, 6 rpm)	35,000 to 60,000 cp @ 25°C	(29)

Emulsions:

A heterogeneous emulsion consists of a continuous liquid external phase in which a discontinuous, immiscible liquid internal phase is dispersed. The internal phase exists as discrete globules that are held in suspension by the action of surface tension in the external phase. The metal or hydride is contained in the internal phase and can settle to the bottom of the droplets but is prevented from settling further due to the interface between the internal and external phases. As long as the emulsion does not break, the particles cannot settle out. The yield stress of an emulsion is the point at which the internal phase globules can "flow" and does not necessarily represent the point at which settling will occur. (29)

Problem Areas:

1. Selection of gelling or emulsifying agent
2. Compatibility of components
3. Mechanical and chemical stability
4. Batch-to-batch uniformity

Remarks:

Additional information can be found in (28), (29) and "Bulletin of the 7th Liquid Propulsion Symposium," Volume 1, 19-21 October 1965, CPIA Publication No. 72, August 1965. (Confidential)

Military Specification, Mil-P-27412, Propellant, Aluminum Hydrazine

III. LIQUID PROPELLANT PROPERTIES

(Oxidizers)

OXYGEN

Formula: O_2

Physical Properties:

Boiling Point:	-183.0°C	(1)
Freezing Point:	-218.8°C	(1)
Density	1.14 g/cc @ -183°C	(1)
Heat of Formation:	-3.08 Kcal/mole @ 90.2°K	(3)
Vapor Pressure:	---	
Critical Temperature:	-118.9°C	(1)
Critical Pressure:	49.7 atm	(1)
Heat of Vaporization:	1.63 Kcal/mole @ 1 atm	(1)
Viscosity:	0.190 cp @ -183.0°C	(1)
Specific Heat:	0.406 cal/gm°C @ -183.0°C	(1)

Preparation: Liquid oxygen is obtained from liquid air by fractional distillation. (9)

Toxicity: Non-toxic. If liquid oxygen spills on skin, injury resembling a burn will result. Oxygen gas will not cause toxic effects in propellant operations, except that inhalation of very cold oxygen gas may cause some irritation of the upper respiratory tract. (7)

Sensitivity: Liquid oxygen is chemically stable. It is not shock sensitive and will not decompose. (7)

Compatibility: Materials to be used in liquid oxygen equipment must possess satisfactory physical properties at extremely low operating temperatures. Acceptable materials are: stainless steel series 18-8, copper, bronze, brass, Monel, aluminum, everdur, Teflon, Kel-F, Asbestos and special silicone rubbers. Petroleum-base lubricants must not be used. Special lubricants such as the fluorolubes or the perfluorocarbons can be used. (7)

Availability: Liquid oxygen is readily available at $38.25 per bulk-ton.

Military Specification, Mil-P-25508, Propellant, Oxygen

FLUORINE

Formula: F_2

Physical Properties:

Boiling Point:	-189°C	(1)
Freezing Point:	-219.6°C	(1)
Density:	1.505 g/cc @ -188°C	(1)
Heat of Formation:	-3.467 Kcal/mole @ 85.2°K	(3)
Vapor Pressure:	---	
Critical Temperature:	-129.2°C	(1)
Critical Pressure:	55 atm	(1)
Heat of Vaporization:	1.560 Kcal/mole @ -188°C	(1)
Viscosity:	0.24 cp @ -188°C	(1)
Specific Heat:	0.367 cal/gm°C @ -188°C	(1)

Preparation: Fluorine is produced from a molten mixture of HF and KF by an electrolytic procedure. (9)

Toxicity: If liquid fluorine comes in contact with the body, it will cause skin injuries resembling burns that are likely to be severe, deep and slow in healing. Exposure to fluorine gas is a more likely accident. The gas is highly irritating to the eyes and to the upper and lower respiratory tract. Repeated exposure to the gas may cause chronic pulmonary damage. The threshold limit value of fluorine is 0.1 ppm (0.2 mg/cu m). (7)

Sensitivity: Unconfined fluorine is stable to shock, heat and electrical spark. Containers of fluorine, however, must not be subjected to shock or heat, as a violent reaction with the container is possible. (7)

Compatibility: Liquid compatible with: Monel, aluminum, stainless steel (types 304L, 321 and 347), copper and brass. Gaseous fluorine compatible with: nickel, Monel, steel, stainless steel, brass, copper, aluminum and magnesium. Teflon, Kel-F and Halon are acceptable non-metals for use at moderate pressures and low flow rates. Spray coated or calcined aluminum oxide is resistant to gaseous and liquid fluorine under flow conditions and at low as well as high temperatures (several hundred degrees C). There are no plastics acceptable for use with liquid fluorine under flow conditions. There are no reliable lubricants for fluorine service. (7)

Availability: Cost: $3.55 a pound, Projected cost: $1.00 a pound. (9)

Military Specification, Mil-P-27405, (Unapproved)

IRFNA

Formula: $H_{0.879}N_{0.972}O_{2.799}$

Physical Properties:		
Boiling Point:	65.6°C	(1)
Freezing Point:	-50°C	(1)
Density:	1.564 g/cc @ 15°C	(1)
Heat of Formation:	-41 Kcal/mole	(1)
Vapor Pressure:	---	
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	0.863 cp @ 21.2°C	(1)
Specific Heat:	0.417 cal/gm @ 20°C	(1)

Preparation: Nitric acid is made by the catalytic oxidation of ammonia with air or oxygen to yield nitric oxide (NO). The latter is oxidized to N_2O_4 which when treated with water, yields nitric acid and may be concentrated by distillation with sulfuric acid. Red fuming nitric acids may be produced by passing gaseous N_2O_4 into nitric acid. (9) The % composition of IRFNA is as follows:

	NO_2	H_2O	HNO_3	Solids	HF
Type IIIA	14	1.5-2.5	81.6-84.8	0.10 max	0.7
Type IIIB	14	1.5-2.5	81.6-84.8	0.04 max	0.7

Toxicity: Because the liquid is highly corrosive, skin and eyes can be severely burned by more than momentary contact. Another serious hazard in the handling of fuming nitric acids is the inhalation of toxic vapors, especially nitrogen dioxide. The threshold limit value of nitrogen dioxide is 5 ppm. The chief danger from acute poisoning is the development of pulmonary edema, when the lung spaces fill with fluid. The symptoms may be delayed for several hours. The color of the fumes is not a reliable index of the degree of toxic hazard. The initial symptoms of poisoning - irritation of the eyes and throat, cough, tightness of the chest and nausea - are slight and may not be noticed. Then some hours later, severe symptoms begin; their onset may be sudden and precipitated by exertion. Coughing, a feeling of constriction in the chest and difficult breathing develop. (7)

Sensitivity: Nitric acid is stable to all types of mechanical shock and impact. (7)

Compatibility: The following metals may be used with nitric acid: aluminum (types 1060, EC, 1100, 3003, 3004, 6061, 5052 and 5154) and stainless steel (347, 19-9DL, 19-9DX, 304 ELC, 321, 303 and 316).

All other ferrous and nonferrous metals and their alloys are prohibited. The following nonmetals may be used: Kel-F, Teflon, polyethylene and Resin-X. The following lubricants may be used: Nordcoseil-147-5, Fluorolube and Perfluorocarbons. (7)

Availability: IRFNA is readily available at from $.06 to $.10 per pound depending upon type and quantity.

Remarks: For additional information consult reference (7) on the latest military specification.

Military Specification, Mil-P-7254, Propellant, Nitric Acid

HYDROGEN PEROXIDE

Formula: H_2O_2 (100%)

Physical Properties:

Boiling Point:	150.2°C	(1)
Freezing Point:	-0.461°C	(1)
Density:	1.4425 g/cc @ 25°C	(1)
Heat of Formation:	-44.75 Kcal/mole @ 25°C	(1)
Vapor Pressure:	.0263 psia @ 20°C	(1)
	0.5762 psia @ 70°C	(1)
Critical Temperature:	457°C	(1)
Critical Pressure:	214 atm	(1)
Heat of Vaporization:	12.334 Kcal/mole @ 25°C	(1)
Viscosity:	1.249 cp @ 20°C	(1)
Specific Heat	0.632 cal/gm @ 25°C	(1)

Preparation: Hydrogen peroxide is manufactured commercially by several processes. Inorganic processes employ the electrolysis of an aqueous solution of sulfuric acid or acidic ammonium bisulfate, followed by hydrolysis of the peroxydisulfate which is formed. Organic processes include (1) the auto-oxidation of hydroquinone or one of its homologues in a suitable solvent system and (2) the partial gas-phase oxidation of hydrocarbons. Dilute aqueous hydrogen peroxide is concentrated to about 90% by conventional distillation. Higher strength solutions are prepared by fractional crystallization of 90% feed stock. (9)

Toxicity: Contact with the liquid, mist or vapor produces irritant effects. When the liquid touches the skin, there is a burning sensation and the affected areas are bleached. Prolonged contact can cause burns. Inhaling the vapor irritates the respiratory tract and may result in burning of the nose and throat, running of the nose and coughing. The vapors can also irritate the eyes. Exposure to high concentrations of a mist or aerosol of hydrogen peroxide, if not washed away promptly, can result in delayed but severe damage to the eyes. The threshold limit value of 90% hydrogen peroxide is 1 ppm. (7)

Sensitivity: Pure hydrogen peroxide in properly passivated containers decomposes at a very slow rate. If stored in containers of unsuitable material or if contaminated, hydrogen peroxide can decompose very rapidly, releasing large amounts of heat and gas. (7)

Compatibility: Proper selection and passivation of materials for handling hydrogen peroxide are essential. Contact of the peroxide with incompatible metals or plastics or with nonpassive surfaces anywhere in the storage system can lead to dangerous conditions. Certain aluminums, the 300-series stainless steels and other materials have only a slight effect on the stability of hydrogen peroxide and may be used for materials of construction. Tanks for long-term storage (one week or

more) are constructed of 1060, 1260, 5254 or 5652 aluminum. Teflon and Kel-F are suitable for flexible long-term storage containers; for periods of less than one week, some polyvinyl chloride plastics and silicone rubbers may be used. Wrought AISI 300-series stainless steels are suitable for short-term storage. (7)

Availability: Available at $.31 to $.43 per pound.

Military Specification, Mil-P-16005, Propellant, Hydrogen Peroxide

CHLORINE TRIFLUORIDE

Formula: ClF_3

Physical Properties:

Boiling Point:	11.75°C	(1)
Freezing Point:	-76.3°C	(1)
Density:	1.8806 g/cc @ 1.70°C	(1)
Heat of Formation:	-42.94 Kcal/mole	(3)
Vapor Pressure:	495 mm Hg @ 0°C	(1)
Critical Temperature:	174°C	(1)
Critical Pressure:	57 atm	(1)
Heat of Vaporization:	6,580 cal/mole @ 11.75°C	(1)
Viscosity:	4.78 cp @ 11.75°C	(1)
Specific Heat:	0.303 cal/gm @ 20°C	(3)

Preparation: ClF_3 is prepared by direct combination of the elements. (9)

Toxicity: The liquid is highly corrosive; contact with skin or eyes could result in deep, painful burns. Exposure to the vapor causes irritation of the eyes and the upper and lower respiratory tracts. If concentrations are high enough, pulmonary edema may result and death may follow if quick action is not taken. Threshold limit is 0.1 ppm. (7)

Sensitivity: CTF is stable to shock, heat and electrical spark. (7)

Compatibility: Such metals as copper, silver-solder, brass, steel, magnesium, aluminum, Monel or nickel are satisfactory for use with CTF owing to the formation of a passivating fluoride film. Monel, 18-8 stainless steel and nickel are preferred. Approved nonmetals, which may ignite when heated are: Neoprene (for protective clothing only), Kel-F (not recommended for flow conditions), Teflon (not recommended for flow conditions) and pyrex glass. The use of the standard petroleum-base lubricant is prohibited. Fluorinated hydrocarbons may react violently with CTF. No completely satisfactory lubricant is known. (7)

Availability: Present cost: $3.20 per pound. Large scale production could reduce cost to $.50/lb. (9)

Military Specification, Mil-P-27411, Propellant, Chlorine Trifluoride (Unapproved)

NITROGEN TETROXIDE

Formula: $N_2O_4 \rightleftharpoons 2NO_2$

Physical Properties:

Boiling Point:	21.3°C	(1)
Freezing Point:	-11.35°C	(1)
Density:	1.45 g/cc @ 20°C	(1)
Heat of Formation:	-4.5 Kcal/mole	(26)
Vapor Pressure:	5.0 psia @ 0°C	(1)
	14.0 psia @ 20°C	(1)
Critical Temperature:	158°C	(1)
Critical Pressure:	100 atm	(1)
Heat of Vaporization:	9.11 Kcal/mole @ 21.15°C	(1)
Viscosity:	4132 micropoise @ 21.15°C	(1)
Specific Heat:	0.368 cal/gm @ 20°C	(1)

Preparation: Nitrogen dioxide is made by the catalytic oxidation of ammonia; steam is used as a diluent to reduce the combustion temperature. Most of the water is condensed out, and the gases are further cooled; the nitric oxide is oxidized to nitrogen dioxide, and the remainder of the water is removed as nitric acid. The gas is essentially pure nitrogen tetroxide, which is then condensed. (9)

Toxicity: The liquid is corrosive and severe burns of the skin and eyes can result if not immediately removed. The inhalation of toxic vapors is normally the most serious hazard in handling nitrogen tetroxide. The threshold limit of the fumes is 5 ppm expressed as nitrogen dioxide, or 2.5 ppm expressed as nitrogen tetroxide. The main danger from acute poisoning is the development of pulmonary edema which normally develops a considerable time after exposure to the fumes. The color of the fumes is not a reliable index of degree of toxic hazard. The initial symptoms of poisoning - irritation of the eyes and throat, cough, tightness of the chest and nausea - are slight and may not be noticed. Severe symptoms begin hours later. Repeated exposure to these fumes at low concentration levels may cause ulceration of the nose and mouth, wearing down and decay of teeth and chronic irritation of the entire respiratory tract. (7)

Sensitivity: Nitrogen tetroxide is very stable at room temperature. At 302°F it begins to dissociate into nitric oxide and free oxygen. Upon cooling it reforms into nitrogen tetroxide. (7)

Compatibility: Nitrogen tetroxide is not corrosive to most common metals at ordinary temperatures and pressures. The selection of metals should however be governed by the oxidizer's moisture content. When the NO_2 moisture content is 0.1% or less the following metals can be used: carbon steels, aluminum, stainless steels, nickel and Inconel. Under wet conditions stainless steel (300 series) should be used. The

following nonmetals may be used: ceramic (acid resistant), pyrex glass, Teflon, Kel-F, asbestos (cotton-free) and polyethylene (limited use). Hydrocarbon lubricants must be avoided. Fluorolube series, Teflon tape, Nerdcoseal-147 and DC2345 lubricant may be used. (7)

Availability: Readily available at $0.09/lb.

Military Specification, Mil-P-26539, Propellant, Nitrogen Tetroxide

PERCHLORYL FLUORIDE

Formula: ClO_3F

Physical Properties:

Boiling Point:	-46.8°C	(1)
Freezing Point:	-146°C	(1)
Density:	1.692 g/cc @ -46.8°C	(1)
Heat of Formation:	-5.12 Kcal/mole (g) @ 25°C	(1) (2)
	-10 Kcal/mole (l)	(3)
Vapor Pressure:	---	
Critical Temperature:	95.2°C	(1)
Critical Pressure:	53.0 atm	(1)
Heat of Vaporization:	4.6 Kcal/mole @ -46.8°C	(1)
	3.5 Kcal/mole @ 25°C	(1)
Viscosity:	0.219 cp @ 0.0°C	(1)
Specific Heat:	0.226 cal/mole°C @ -46.46°C	(1)

Preparation: Perchloryl fluoride may be prepared by the electrolysis of a mixture of sodium perchlorate ($NaClO_4$) and hydrofluoric acid (HF). Fluorination of $KClO_3$ will also yield the oxidizer. (9)

Toxicity: Should liquid PF splash onto the skin, irritation or moderate to severe burns may result, depending on the amount spilled and the length of time it remains on the skin. Exposure to moderate to high concentrations of the vapor causes respiratory irritation and methemoglobinemia, which, if severe, is accompanied by cyanosis (blue tinge to certain mucous membranes). Repeated exposure to lower concentrations may cause anemia and the deposit of fluoride in bones and teeth. The threshold limit for perchloryl fluoride is 3 ppm. (7)

Sensitivity: Perchloryl fluoride is thermally stable up to 850°F. At 500 to 575°F, it hydrolyzes slowly with water to form $HClO_4$ and HF at room temperature. (7)

Compatibility: Although at ordinary temperatures perchloryl fluoride is not corrosive to most common metals, moisture content of the PF should be the governing factor in selecting a metal for this service. The following metals are approved for use with Anhydrous PF: carbon steel, aluminum, stainless steel, copper, brass and bronze. For PF and water vapor the following can be used: stainless steel (types 304, 310 and 314), Hastelloy, tantalum, Durimet "T" and Durimet-20. Owing to the lack of operational and long term data, the only non-metal materials that can be recommended for severe service with PF in a situation where pressure or flow phenomena may irritate combustion or detonation are Kel-F and Teflon. Perchloryl fluoride

should never be brought into contact with conventional or petroleum greases, oils, pipe compounds, etc. The only lubricants found to be suitable are the fluorocarbons. (7)

Availability: Perchloryl fluoride is available in small quantities from several chemical companies. Projected cost: $1.50 per pound. (9)

Military Specification, None

OXYGEN DIFLUORIDE

Formula: OF_2

Physical Properties:

Boiling Point:	-145.3°C	(5)
Freezing Point:	-223.8°C	(5)
Density:	1.546 g/cc @ -148.52°C	(5)
Heat of Formation:	-7.4 Kcal/mole	(26)
Vapor Pressure:	---	
Critical Temperature:	-59.7°C	(5)
Critical Pressure:	49.5 atm	(5)
Heat of Vaporization:	2.66 Kcal/mole @-145.3°C	(5)
Viscosity:	0.323 cp @ -155.8°C	(5)
Specific Heat:	10.35 cal/mole°C @ 298°C	(5)

Preparation: Oxygen difluoride is prepared by reacting elemental fluorine with dilute aqueous solution of sodium or potassium hydroxide, according to the following reaction:

$$2NaOH + 2F_2 \longrightarrow OF_2 + 2NaF + H_2O$$

Only 50 percent of the original fluoride, at best, is recovered as the oxygen difluoride. (9)

Toxicity: Precise and accurate data defining the toxicity of OF_2 is not available. Oxygen difluoride is a lethal gas, comparable to phosgene, and has a peculiar smell similar to that of elemental fluorine. It penetrates deep into the lungs by passing the bronchin and dissolves in the delicate tissues. The full effect develops sometime after inhalation producing a delayed edema. The symptoms are evidenced by a difficulty in breathing, irresistible coughing, emetic irritation, as well as a general tight feeling in the chest. A practical operating guide is to limit personnel exposures to the levels practiced in handling pentaborane 0.005 ppm. (5)

Sensitivity: Oxygen difluoride is insensitive to shock at -196°C using the Trauzl sensitivity test. The decomposition of OF_2 is appreciable only above 250°C. (5)

Compatibility: Cleanliness and smooth surfaces are important for successful operation with OF_2.

Liquid OF_2 compatibility:

- Aluminum alloys for short term applications
- Nickel alloys are perhaps most satisfactory (e.g. Monel)
- Stainless steels are most widely used for construction, however, long term servicability has not been established
- Copper and copper alloys, titanium alloys and magnesium alloys seem to have limited adaptability to long-term liquid operations

Plastics and elastomeric materials are limited because of cryogenic temperatures

Teflon and Kel-F are compatible for short periods of time. Gaseous OF_2 service requirements do not appear to be more severe than the liquid requirement. At elevated temperatures, however, the decomposition into fluorine and oxygen must be taken into consideration. (5)

Availability: Currently the only source of commercial quantities of OF_2 is the Allied Chemical Corporation. The present cost is $35 per pound available in nine pound cylinders. The lowest price forecast based on synthesis from fluorine is $30/lb. Thiokol-RMD has conducted a cost analysis on an electrolytic OF_2 process based on HF resulting in cost estimates as low as $.50/lb for large scale production. (5)

Remarks: For additional information consult reports resulting from Contract AF 04(611)-8400. Reference (5) lists 49 additional references.

Military Specification, None

TETRAFLUOROHYDRAZINE

Formula: N_2F_4

Physical Properties:

Boiling Point:	-74°C	(18)
Freezing Point:	-163°C	(18)
Density:	1.65 g/cc @ -73.0°C	(18)
Heat of Formation:	-2.0±2.5 Kcal/mole (g)	(18)
	-5 Kcal/mole (l)	(3)
Vapor Pressure:	---	
Critical Temperature:	36°C	(18)
Critical Pressure:	41.5 atm	(18)
Heat of Vaporization:	3710 cal/mole	(18)
Viscosity:	---	
Specific Heat:	19.06 cal/mole°C @ 25°C	

Preparation:

1. Pyrolysis of nitrogen trifluoride over various metals such as stainless steels, copper and arsenic.
2. Homogeneous reaction of nitrogen trifluoride with mercury in an electric discharge.
3. Vapor phase reaction of fluorine and ammonia in a packed copper reactor.
4. Thermal pyrolysis of nitrogen trifluoride over carbon. (18)

Toxicity: Tetrafluorohydrazine must be considered highly toxic and hazardous to humans. Skin contact and inhalation must be avoided. Studies on rats demonstrated that it causes respiratory irritation and methemoglobinemia. Pulmonary edema and kidney damage were also detected. Repeated exposures are insidious, producing systemic damage even at low concentrations. (18)

Sensitivity: Tetrafluorohydrazine has been involved in countless explosions. Extreme caution should be exercised when dealing with this compound especially when impurities are present. (18)

Compatibility: At moderate temperatures the following materials have been used successfully with N_2F_4: pyrex glass, nickel, copper, carbon steel, polyethylene, stainless steel, brass, Monel, Teflon and Kel-F. Nickel and Monel are recommended for high temperature work. Pyrex glass and stainless steel have been used successfully at liquid nitrogen temperatures. (18)

Availability: Available only by contract. Air Products has the only plant now in existence. No cost data available.

Remarks: Additional references cited in ref (18).

Military Specification, None

COMPOUND A

Formula: ClF_5

Physical Properties:

Boiling Point:	-13.1°C	(19)
Freezing Point:	-103°C	(19)
Density:	1.793 g/cc @ 20°C	(19)
Heat of Formation:	-60±5 Kcal/mole	(19)
Vapor Pressure:	---	
Critical Temperature:	143°C	(19)
Critical Pressure:	52.3 atm	(19)
Heat of Vaporization:	5.313 Kcal/mole @ -13.1°C	(19)
Viscosity:	3.245 cp @ 20°C	(19)
Specific Heat:	0.3355 cal/gm°K @ 20°C	(19)

Preparation: Chlorine pentafluoride is prepared by a continuous process, homogeneous gas-phase reaction of elemental fluorine and chlorine. The current production facility has a maximum operating range of 2000 psig and 600°F. The reaction normally is carried out at 200°F and between 1000 and 1500 psig. (19)

Toxicity: No limits have been established at the present time. It should be treated similar to chlorine trifluoride which has a threshold limit of 0.1 ppm. (19)

Sensitivity: All tests have shown ClF_5 to be insensitive to initiation and will not propagate a detonation. (19)

Compatibility: Compound A has been tested with Monel, nickel, Inconel-X, Hastelloy C, aluminum, stainless steel, copper and Teflon. Essentially all materials tested were compatible in uncontaminated ClF_5. When ClF_5 or the materials were contaminated with moisture only Hastelloy C of nickel 200 provided complete resistence to attack. No change in composition of the ClF_5 occurred in any of the tests was detectable. (19)

Availability: Currently ClF_5 is not commercially available because of its classification. Several companies will supply small quantities at an estimated cost of $50 per pound to government contractors. Projected cost in large quantities is between $0.50 and $1.00 per pound.

Remarks: Consult reports generated under Contract AF 04(611)-7023 and Contract AF 04(611)-9563 for additional information.

Military Specification, None

OZONE

Formula: O_3

Physical Properties:

Boiling Point:	-111.9°C	(1)
Freezing Point:	-192.7°C	(1)
Density:	1.66 g/cc @ -112°C	(1)
	1.571 g/cc @ -183°C	(1)
Heat of Formation:	+34.4 Kcal/mole @ 25°C	(3)
Vapor Pressure:	---	
Critical Temperature:	-12.1°C	(1)
Critical Pressure:	54.6 atm	(1)
Heat of Vaporization:	3,410 cal/mole @ -111.9°C	(1)
Viscosity:	1.56 cp @ -183.0°C	(1)
Specific Heat:	17 cal/mole @ -111.9°C	(1)

Preparation: Purified oxygen is fed into an electric discharge or between highly charged plates. The reaction $3O_2 \longrightarrow 2O_3$ takes place leaving a concentration of from 1 to 6 weight percent ozone. This mixture is introduced into a refrigerated vessel where the ozone condenses out at -111.9°C and 1 atm partial pressure. (1)

Toxicity: The reaction on the human skin is similar to that of liquid oxygen and the coldness will cause severe "burns". Liquid ozone at temperatures above the boiling point of liquid oxygen will give off high concentrations of gaseous ozone and there is the danger of building up to a toxic concentration. Concentrations of 1 ppm may be readily detected by the human nose. The maximum allowable concentration for an eight hour period is 0.1 ppm. Concentrations up to 20 ppm may be considered nontoxic if the exposure time is short. (1)

Sensitivity: One estimate of the stability of liquid ozone is that at -183°C its sensitivity is comparable to that of nitroglycerin at room temperature. Gaseous ozone at room temperature appears to be less stable than liquid ozone. Very pure ozone (impurities of less than 2ppm) has shown measurable, spontaneous decomposition at room temperature in clean glass containers. (1)

Compatibility: The following materials have been shown to be compatible with 100% ozone (gaseous and liquid): aluminum (25, 35, 245, 525 and 615), stainless steel (302, 304, 316, 410 and 416), Kel-F, Teflon, Fluorocarbon greases, Kovar, pyrex and silver solders. Some materials are compatible with liquid ozone but not with the gas. (1)

Availability: Because of stability problems associated with concentrated ozone, it is costly, hazardous to concentrate and difficult to transport and store. Concentrated ozone in either gaseous or liquid form is usually produced and used as needed. (1) The projected cost of ozone if required in large quantities is $0.09.

Remarks: Additional information is contained in Thorp, C. E., Bibliography of Ozone Technology, Vol 2, Armour Research Foundation, Chicago, Illinois (1955).

Military Specification, None

MOXY 2

Composition: A mixture of tris (difluoramino) fluoromethane (Compound R), tetrafluorohydrazine (N_2F_4) and perchloryl fluoride (ClO_3F). (20)

MOXY-2a

$R/N_2F_4/ClO_3F$ :: 30.3/61.8/7.9 mole %

Physical Properties:

Boiling Point:	about -80°C	(20)
Freezing Point:	very viscous at -135°C	(20)
Density:	1.446 g/cc @ 0°C	(20)
	1.335 g/cc @ 25°C	(20)
Heat of Formation:	-19.7 Kcal/mole	(20)
Critical Temperature:	85°C	(20)
Viscosity:	0.268 cp @ 0°C	(20)

Preparation: $FC(NF_2)_3$ is prepared by the direct fluorination of ammeline. The mixture is prepared by condensing the components together in a closed vessel. (20)

Toxicity: Preliminary tests indicate that Moxy-2 toxicity should be based on the component N_2F_4. No threshold value has been set. (20)

Sensitivity: Moxy 2a is less sensitive than n-propyl nitrate as tested in an adiabatic U-tube tester, however, it is sensitive to change in flow conditions, especially at sharp turns in lines while the mixture is flowing.

Compatibility: Platinum was the only metal showing no attack whatsoever after exposure to the oxidizer at 43°C for a period of several weeks. Stainless steels 347 and 316, Monel and pure aluminum developed light colored films. Stainless steel 304, iron, copper, nickel, Hastelloy B, aluminum E.C. alloy and tantalum exhibited moderate surface attack by formation of fairly heavy surface coatings, all of which could be scraped off. Teflon is the most satisfactory of the nonmetals tested, while Butyl and Buna-N are marginal. (20)

Availability: There is no known source producing Moxy 2a at this time.

Remarks: For additional information consult reports generated under Contract AF 04(611)-8182. Initial small engine test firings with Moxy 2a and N_2H_4 showed that this oxidizer was too shock sensitive to safely handle.

Military Specification, None

TETRAKIS (DIFLUORAMINO) METHANE

(Compound T) (Delta)

Formula: $C(NF_2)_4$

Physical Properties:

Boiling Point:	40.2°C	(13)
Freezing Point:	-20°C	(13)
Density:	1.65 gm/cc @ 25°C	(13)
Heat of Formation:	+13±5 Kcal/mole	(17)
Vapor Pressure:	---	
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	6.4 Kcal/mole	(13)
Viscosity:	---	
Specific Heat:	---	

Preparation:

a. Minnesota Mining & Manufacturing Company synthesis:

$$(F_2N)_2C = NF + NH_3 \xrightarrow[T]{\text{Low}} (F_2N)_2\overset{\overset{HNF}{|}}{C} - NH_2$$

$$(F_2N)_2\overset{\overset{HNF}{|}}{C} - NH_2 \xrightarrow[\text{Low T}]{F_2} C(NF_2)_4$$

b. American Cyanamid Company synthesis:

$$(F_2N)_2C = NF + HNCO \longrightarrow (F_2N)_2\overset{\overset{HNF}{|}}{C} - NCO$$

$$(F_2N)_2\overset{\overset{HNF}{|}}{C} - NCO + F_2 \xrightarrow[-30°C]{He} C(NF_2)_4 \qquad (13)$$

Toxicity: Compound "T" should be considered to be as toxic as chlorine trifluoride.

Sensitivity: This compound is highly shock sensitive.

Compatibility: Compatibility should resemble that of chlorine trifluoride.

Availability: Not commercially available. It has only been made in gram quantities in the laboratory.

Military Specification, None

IV. LIQUID PROPELLANT PROPERTIES

(Monopropellants)

MONEX D

Formula: A thixotropic mixture of beryllium (16.6%), hydrazine nitrate (28.7%), hydrazine (37.5%) and water (17.0%). This composition along with 0.3% gelling agent has been designated MONEX DW 17 G.3

Physical Properties:

Freezing Point:	-57.3°C	(30)
Density:	1.229 g/cc @ 25°C	(30)
Vapor Pressure:	9 mm Hg @ 25°C	(30)
Specific Impulse:	306 sec	(30)

Preparation: The composition is formed by mixing the components together in a moisture free atmosphere.

Toxicity: Monex D is very toxic due to the presence of beryllium. Beryllium handling methods and precautions must be used when working with this propellant.

Sensitivity: Monex DW 17 G.3 has been found to be insensitive to shock using the standard impact sensitivity test, the card-gap test and thermal stability test for monopropellants. During preparation, however, the sensitive nature of hydrazine nitrate must be considered.

Compatibility: The compatibility of Monex D is determined by its components. Materials usable with hydrazine should be compatible with Monex.

Availability: Monex is still in the development stage. Only laboratory samples have been prepared to date.

Remarks: For additional information consult reports resulting from Contract AF 04(611)-9713.

Military Specification, None

V. LIQUID PROPELLANT

THEORETICAL PERFORMANCE SUMMARY

SUMMARY OF MAXIMUM THEORETICAL SPECIFIC IMPULSE
(1000/14.7 psia)
(Shifting Equilibrium)

	N_2H_4	MMH	UDMH	50/50	RP-1	H_2	NH_3	B_5H_9	B_2H_6	MHF-1	MHF-3	MHF-5	MAF-1	Hyb A4	Hyb A5	Hyb B3
Oxygen	313	306	310	312	300	391		327	349	301	312	307	303	324	326	330
Fluorine	363	346	344	349	318	410	357	360	363	348	347	352	303			
IRFNA	278	278	272	272				298							297	305
Hydrogen Peroxide	286	285	283	283		322	263	316	334	278	281	284	281	305	309	313
Chlorine Trifluoride	293	283	280	283		318		290			282	285	270	286		
Nitrogen Tetroxide	291	288	286	289	277	342	262	306	321	282	288	287	281	302	306	316
Perchloryl Fluoride	295	291	290			344		306								
Oxygen Difluoride	339	343		342	341	401		354	365					349		
Tetrafluoro-hydrazine	334	327			297			334								
Chlorine Pentafluoride	311	298	292	300	269					295	299	303	287	302		
Ozone	334				329	427										
Moxy 2	315	305	301	307	287	343				310	306	303	294			
Compound "T" - N_2C_2	326															
$O_2/F_2/O_3$ 30/10/60	329				323	415										
N_2H_4								324								

SUMMARY OF MAXIMUM THEORETICAL SPECIFIC IMPULSE (Cont.)

(1000/14.7 psia)

(Shifting Equilibrium)

	N_2H_4-Al-33	N_2H_4-Al-43	N_2H_4-B-25	N_2H_4-Be-35	N_2H_4-Be-45	MMH-Be-45	N_2H_4-AlH_3-25	N_2H_4-AlH_3-35	N_2H_4-AlH_3-45	MMH-BeH_2-45
Oxygen	314	310								353
Hydrogen Peroxide	301	304	333	332	323	323	299	307	316	349
Chlorine Trifluoride	290	287	304	303	305		296	295	295	307
Nitrogen Tetroxide	304	299	325	315	304		305	312	316	336
Chlorine Pentafluoride	306	303	320	317	317		313	313	312	323
Moxy [illegible]	313									

SUMMARY OF MAXIMUM THEORETICAL DENSITY IMPULSE

(1000/14.7 psia)

(Shifting Equilibrium)

	N_2H_4	MMH	UDMH	50/50	RP-1	H_2	NH_3	B_5H_9	MHF-1	MHF-3	MHF-5	MAF-1	Hyb A4	Hyb A5	Hyb B3
Oxygen	335		304	319		159		302	336	319	330	313	313	310	301
Fluorine	478		413	444		297		454	461	440	463	313			
IRFNA														355	349
Hydrogen Peroxide	363		354	354		209	302	367	361	359	365	360	369		365
Chlorine Trifluoride	436	282	385	414		289		446		411	431	387	446		
Nitrogen Tetroxide	352		336		378	183	283	346	355	351	355	346	353	349	341
Perchloryl Fluoride	295	289	285			267		300							
Oxygen Difluoride													442		
Chlorine Pencafluoride	454	421	397	426	387				452	427	442	397	447		
Ozone	395				390										
Moxy 2	392	368	355	374	344				387	373	382	353			
Compound "T" - * N_2O_4	467														

* ½ mole N_2O_4 per mole Cmpd "T"

SUMMARY OF MAXIMUM THEORETICAL DENSITY IMPULSE (Cont.)

(1000/14.7 psia)

(Shifting Equilibrium)

	N_2H_4-Al-33	N_2H_4-Al-45	N_2H_4-Be-25	N_2H_4-Be-35	N_2H_4-Be-45	MMH-Be-45	N_2H_4-AlH_3-25	N_2H_4-AlH_3-35	N_2H_4-AlH_3-45	MMH-BeH_2-45
Oxygen	385	402								342
Hydrogen Peroxide	405	425	410	428	434	415	387	394	402	340
Chlorine Trifluoride	477	489	496	507	517		474	482	488	462
Nitrogen Tetroxide	403	421	405	411	414		482	391	399	375
Chlorine Pentafluoride	491	499	500	515	523		480	492	498	468
Moxy 2	414									

VI. THEORETICAL PERFORMANCE DATA

for

FUELS WITH VARIOUS OXIDIZERS

Hydrazine		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 100/Vac	A_e/A_t Vac.
Oxygen	(23)	313	6060	5680	0.923	1.07	335	0.923	297	361	43.7
Fluorine	(23)	363	6970	7980	2.23	1.31	478	2.45	333	395	31.8
IRFNA	(24)	278		4946	1.50	1.28					
Hydrogen Peroxide	(23)	286	5660	4800	2.03	1.26	363	2.12	279	337	39.7
Chlorine Trifluoride	(23)	293	5810	6530	2.70	1.48	436	2.70	278	337	32.8
Nitrogen Tetroxide	(23)	291	5610	5410	1.32	1.21	352	1.38	280	342	39.0
Perchloryl Fluoride	(24)	295	5730	5779	1.47	1.22	295	1.56	279	358	39.4
Oxygen Difluoride	(26)	339	6736	6689	1.54	1.27			317		
Tetrafluorohydrazine	(24)	334		7583	3.26	1.44					
Chlorine Pentafluoride	(27)	311	6305	6849	2.51	1.46	454	2.57			
Ozone	(27)	334	6605	6039	0.85	1.18	395	0.98			
Moxy 2	(27)	315	6435	6975	3.08	1.23	392	3.55			
Pentaborane	(27)	324		4464	1.41	0.80	262	1.82			
Compound "T"-N_2O_4*	(27)	326	6620	7425	3.55	1.42	467	4.26		379	40.0

*½ mole N_2O_4 per mole Compound "T"

Monomethyl Hydrazine	Shift's Isp 1000/Sl.	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/Sl.	Max IspD O/F	Frozen Isp 1000/Sl.	Shift's Isp 1000/Vac	A_e/A_t Vac.
Oxygen (24)	306			1.01	0.989					
Fluorine (26)	346	6825	7612	2.50	1.25			318		
IRFNA (24)	278		5284	2.45	1.28					
Hydrogen Peroxide (26)	285	5665	4928	3.44	1.26			278		
Chlorine Trifluoride (24)	283		6105	2.84	1.42	282	3.17			
Nitrogen Tetroxide (24)	288	5710	5643	1.49	1.19					
Perchloryl Fluoride (24)	291		5911	2.23	1.19	289	2.57			
Oxygen Difluoride (26)	343	6819	7202	2.32	1.24			319		
Tetrafluorohydrazine (24)	334		7583	3.26	1.44					
Chlorine Pentafluoride (27)	298	5948	6228	2.57	1.39	421	3.55			
Moxy 2 (27)	305	6090	6566	3.44	1.19	368	4.56			

Uns. Dimethyl Hydrazine (UDMH)		Shift'g Isp 1000/ft.	C^*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max Isp 1000/ft.	Max Isp O/F	Pressure Isp 1000/ft.	Shift'g Isp 1000/sec	A_e/A_c Vac.
Oxygen	(23)	310	5950	6050	1.70	0.977	304	1.86	291	335	35.9
Fluorine	(23)	344	6500	7360	2.45	1.19	413	2.70	314	409	49.5
IRFNA	(24)	272		4955	3.17	1.27					
Hydrogen Peroxide	(23)	283	5520	4960	4.26	1.25	354	4.56	274	337	45.1
Chlorine Trifluoride	(23)	280	5520	6370	3.00	1.37	385	3.17	269	323	40.9
Nitrogen Tetroxide	(23)	286	5520	5720	2.57	1.16	336	2.85	271	316	35.7
Perchloryl Fluoride	(24)	290		6139	2.70	1.17	285	3.35		359	
Chlorine Pentafluoride	(27)	292	5835	6093	2.45	1.31	397	4.56			
Moxy 2	(27)	301	5920	6494	3.65	1.16	355	5.06			

50/50	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen (27)	312	6187	5859	1.27	1.02	319	1.41			
Fluorine (27)	349	6840	7677	2.51	1.26	444	3.00			
IRFNA (27)	272	5420	5049	2.39	1.29					
Hydrogen Peroxide (27)	283	5710	4838	2.77	1.24	354	3.55			
Chlorine Trifluoride (27)	283	5705	5884	2.57	1.44	414	3.65			
Nitrogen Tetroxide (26)	289	5740	5610	2.00	1.21			275		
Oxygen Difluoride (26)	342	6795	7093	2.15	1.25			318		
Chlorine Pentafluoride (27)	300	5971	6334	2.51	1.40	426	3.65			
Moxy 2 (27)	307	6131	6726	3.44	1.20	374	4.71			

RP-1		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen	(26)	300	5895	6164	2.60	1.02			286		
Fluorine	(26)	318	6153	6839	2.62	1.21			295		
Nitrogen Tetroxide	(27)	276	5340	5740	4.00	1.29	357	4.56	262	321	40.6
Oxygen Difluoride	(26)	341	6838	7766	3.82	1.28			315		
Tetrafluorohydrazine	(26)	297	5810	6400	3.60	1.34			275		
Chlorine Pentafluoride	(27)	269	5370	5936	2.77	1.35	387	6.69			
Ozone	(27)	329		6606	2.23	1.16	390	3.08			
Moxy 2	(27)	287	5625	6345	4.56	1.19	344	5.45			

Hydrogen		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 100:1 Vac	A_e/A_t Vac.
Oxygen	(23)	391	7960	4530	3.55	0.264	159	9.00	387	446	31.1
Fluorine	(23)	410	8120	6680	8.09	0.47	297	19.0	387	465	36.9
Hydrogen Peroxide	(23)	322	6570	3870	7.34	0.435	209	15.7	322	373	34.6
Chlorine Trifluoride	(23)	318	6440	5670	11.5	0.610	289	27.6	299	364	30.9
Nitrogen Tetroxide	(23)	342	6980	4330	5.25	0.352	183	11.5	339	396	34.9
Perchloryl Fluoride	(24)	344	7060	4480	5.25	0.352	267	24.0	342	409	36.3
Oxygen Difluoride	(26)	401	8188	5880	6.04	0.39				393	
Ozone	(27)	427	8653	5427	3.76	0.283					
Moxy 2	(27)	343	7128	5329	9.00	0.48					

Ammonia	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Fluorine (24)	357		7718	3.35	1.15					
Hydrogen Peroxide (27)	263	5325	3938	2.77	1.12	302	3.35			
Nitrogen Tetroxide (27)	262	5352	4494	2.03	1.06	283	2.23			

Pentaborane	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen (23)	327	6230	7670	2.33	1.02	302	2.57	313	384	53.0
Fluorine (23)	360	6840	8730	4.56	1.20	454	9.00	328	430	49.1
IRFNA (24)	298		5815	3.35	1.17					
Hydrogen Peroxide (23)	316	6210	5660	2.70	1.06	367	5.66	309	375	61.1
Chlorine Trifluoride (23)	290	5550	7620	7.33	1.47	446	11.5	268	350	52.5
Nitrogen Tetroxide (23)	306	5890	7220	3.35	1.10	346	4.0	293	369	52.5
Perchloryl Fluoride (24)	306		7545	3.76	1.12	300	4.88		390	
Oxygen Difluoride (26)	354	6969	8357	3.88	1.18			328		
Tetrafluorohydrazine (24)	334		8177	7.32	1.38					
Hydrazine (27)	324		4464	1.41	0.80	262	1.82			

Diborane		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen	(24)	349		6928	2.13	0.753					
Fluorine	(24)	363			4.0	1.01					
Hydrogen Peroxide	(24)	334		4725	1.94	0.809					
Nitrogen Tetroxide	(24)	321		6616	3.16	0.925					
Oxygen Difluoride	(26)	365	7209	7764	3.73	1.00			340		

MHF-1	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'd Isp 1000/Vac	A_e/A_t Vac.
Oxygen (27)	301	5970	5639	0.818	1.11	336	0.835			
Fluorine (27)	348	7063	7731	1.70	1.32	461	1.90			
Hydrogen Peroxide (27)	278	5622	4797	1.67	1.29	361	1.99			
Nitrogen Tetroxide (27)	282	5682	5362	1.15	1.25	355	1.33			
Chlorine Pentafluoride(27)	295	6125	6867	2.39	1.50	452	2.51			
Moxy 2 (27)	310	6342	6946	2.45	1.25	387	2.57			

MHF-3	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen (27)	312	6138	5850	1.30	1.02	319	1.44			
Fluorine (27)	347	6855	7549	2.39	1.26	440	3.08			
Hydrogen Peroxide (27)	281	5667	4804	2.77	1.25	359	3.35			
Chlorine Trifluoride (27)	282		5769	2.39	1.42	411	3.76			
Nitrogen Tetroxide (27)	288	5705	5571	2.03	1.21	351	2.23			
Chlorine Pentafluoride (27)	299		6228	2.51	1.39	427	3.26			
Moxy 2 (27)	306	6104	6573	3.26	1.20	373	4.56			

MHF-5	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Pressure Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Oxygen (27)	307	6070	5778	1.02	1.07	330	1.06			
Fluorine (27)	352	7010	7785	2.23	1.31	463	2.57			
Hydrogen Peroxide (27)	284	5672	4874	2.28	1.28	365	2.70			
Chlorine Trifluoride (27)	285		6[illegible]6	2.51	1.51	431	3.00			
Nitrogen Tetroxide (27)	287	5727	5463	1.44	1.23	355	1.67			
Chlorine Pentafluoride (27)	303		6696	2.51	1.46	442	2.77			
Moxy 2 (27)	308	6245	6823	2.92	1.23	382	3.26			

MAF-1		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen	(27)	303	6022	5954	1.60	1.02	313	1.86			
Fluorine	(27)	330	6353	7047	2.28	1.23	416	3.35			
Hydrogen Peroxide	(27)	281	5560	4995	4.56	1.29	360	5.06			
Chlorine Trifluoride	(27)	270	5380	5742	2.45	1.41	387	5.67			
Nitrogen Tetroxide	(27)	281	5608	5742	2.64	1.23	346	3.00			
Chlorine Pentafluoride	(27)	287	5715	6102	2.45	1.37	397	3.35			
Moxy 2	(27)	294	5840	6258	3.17	1.18	353	4.71			

Baseline A4		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Oxygen[a]	(27)	329	6450	6188	1.41	0.942	317	1.86			
Oxygen[b]	(27)	324	6390	6390	1.60	0.955	313	1.94		389	40.0
Hydrogen Peroxide[a]	(27)	310		3780	1.00	0.994	366	4.88			
Hydrogen Peroxide[b]	(27)	305	6000	3753	1.06	1.01	369	5.90		362	40.0
Chlorine Trifluoride[a]	(27)	287	5630	6629	4.26	1.47					
Chlorine Trifluoride[b]	(27)	286	5545	6300	5.06	1.51	446	7.33		342	40.0
Nitrogen Tetroxide[a]	(27)	310		4316	0.724	0.948	358	3.17			
Nitrogen Tetroxide[b]	(27)	302	5890	4212	0.709	0.945	355	3.17		362	40.0
Oxygen Difluoride[a]	(27)	351	6937	7677	3.08	1.23	444	4.56			
Oxygen Difluoride[b]	(27)	349	6900	7720	3.26	1.24	442	4.56		415	40.0
Chlorine Pentafluoride[a]	(27)	304	5995	7209	4.56	1.44	452	7.0			
Chlorine Pentafluoride[b]	(27)	302	5945	7065	4.41	1.43	447	7.33		361	40.0
Moxy 2	(27)	312	6185	7272	5.90	1.20					
[a] Heat of Formation of A4 = -16.5											
[b] Heat of Formation of A4 = -43											

Hybaline A5		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 100:1/Vac	A_e/A_t Vac.
Oxygen[a]	(8)	341	6853	6760	1.50	0.94					
Oxygen[b]	(27)	326	6370	6480	1.63	0.94	310	1.86		388	40.0
IRFNA[a]	(8)	319	6470	4700	1.00	1.01					
IRFNA[b]	(27)	297	5755	4025	0.786	0.958	355	4.13		357	40.0
Hydrogen Peroxide[a]	(8)	316	6435	4320	1.00	0.98					
Hydrogen Peroxide[b]	(27)	309	6055	3810	1.02	0.98				368	40.0
Nitrogen Tetroxide[a]	(27)	313		4385	0.667	0.917	354	3.26			
Nitrogen Tetroxide[b]	(27)	306	5955	4310	0.695	0.922	349	3.35		366	40.0
[a] Heat of Formation of A5 =		-16.5									
[b] Heat of Formation of A5 =		-43									

Hybaline B3		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Oxygen[a]	(8)	338		5785	1.38						
Oxygen[b]	(27)	330	6420	5985	1.70	0.90	301	2.03		392	40.0
IRFNA[a]	(8)	323		4465	0.59						
IRFNA[b]	(27)	305	6030	3935	0.59	0.845	349	4.26		364	40.0
Hydrogen Peroxide[a]	(27)	324		3900	0.96	1.23	358	5.67			
Hydrogen Peroxide[b]	(27)	313	6135	3640	0.89	0.893	365	6.14		372	40.0
Nitrogen Tetroxide[a]	(27)	331		4660	0.61	1.16	347	3.65			
Nitrogen Tetroxide[b]	(27)	316	6270	4375	0.64	0.843	341	4.0		375	40.0
[a] Heat of Formation of B3 = -19.5											
[b] Heat of Formation of B3 = -50											

Hydrazine-Al-(33, 43)	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
33/Oxygen (27)	314	6202	6411	0.481	1.23	385	0.399			
33/Hydrogen Peroxide (27)	301	5963	5202	0.492	1.32	405	1.38			
33/Chlorine Trifluoride (27)	290		7218	2.51	1.65	477	2.57			
33/Nitrogen Tetroxide (27)	304		5760	0.481	1.33	403	1.25			
33/Compound "A" (27)	306	6103	7677	2.51	1.60	491	2.51			
33/Moxy 2 (27)	313	6285	7786	3.08	1.32	414	3.08			
43/Oxygen (27)	310	6046	6759	0.470	1.29	402	0.428			
43/Hydrogen Peroxide (27)	304	5975	5544	0.408	1.40	425	0.428			
43/Chlorine Trifluoride (27)	287	5707	7524	2.64	1.71	489	2.70			
43/Nitrogen Tetroxide (27)	299		6476	0.639	1.41	421	0.639			
43/Compound "A" (27)	303	5990	7900	2.57	1.65	499	2.51			

Hydrazine-Be-(25, 35, 45)	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
25/Hydrogen Peroxide (27)	333	6380	5230	0.49	1.22	410	0.67		398	40.0
25/Chlorine Trifluoride(27)	304	6015	7160	2.85	1.61	496	3.76		360	40.0
25/Nitrogen Tetroxide (27)	325	6280	5985	0.67	1.25	405	0.74		392	40.0
25/Compound "A" (27)	320	6310	7055	1.94	1.50	500	4.00		382	40.0
35/Hydrogen Peroxide (27)	332	6378	5895	0.67	1.29	428	0.70		403	40.0
35/Chlorine Trifluoride(27)	303	5980	7390	3.08	1.65	507	4.13		364	40.0
35/Nitrogen Tetroxide (27)	315	6065	6390	0.85	1.31	411	0.91		381	40.0
35/Compound "A" (27)	317	6105	7898	3.00	1.60	515	4.13		381	40.0
45/Hydrogen Peroxide (27)	323	6205	6200	0.84	1.34	434	0.91		392	40.0
45/Chlorine Trifluoride(27)	305	6050	7590	3.26	1.69	517	3.55		365	40.0
45/Nitrogen Tetroxide (27)	304	5910	6905	1.11	1.36	414	1.17		370	40.0
45/Compound "A" (27)	317	6250	8100	3.44	1.64	523	4.00		381	40.0
wt loading/oxidizer										

MMH-Be-45	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrogen Peroxide (27)	323	6185	5925	1.04	1.28	415	1.13		391	40.0

Hydrazine-AlH_3 (25, 35, 45)	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
25/Hydrogen Peroxide (27)	299	5975	5063	1.27	1.26	387	2.33		352	40.0
25/Chlorine Trifluoride(27)	296	5950	6921	2.85	1.58	474	3.55		348	40.0
25/Nitrogen Tetroxide (27)	305	6085	5648	0.89	1.23	482	1.44		360	40.0
25/Compound "A" (27)	313	6280	7227	2.57	1.52	480	3.17		369	40.0
35/Hydrogen Peroxide (27)	307	6100	4581	0.49	1.21	394	2.33		360	40.0
35/Chlorine Trifluoride(27)	295	5922	6984	2.77	1.59	482	3.76		349	40.0
35/Nitrogen Tetroxide (27)	312	6220	5202	0.49	1.21	391	1.27		367	40.0
35/Compound "A" (27)	313	6240	7668	3.00	1.56	492	3.55		364	40.0
45/Hydrogen Peroxide (27)	316	6255	4878	0.42	1.23	402	1.90		373	40.0
45/Chlorine Trifluoride(27)	295	5880	7173	3.00	1.62	488	4.13		349	40.0
45/Nitrogen Tetroxide (27)	316	6240	5724	0.61	1.25	399	0.89		376	40.0
45/Compound "A" (27)	312	6235	7650	3.26	1.59	498	3.76		365	40.0
wt loading/oxidizer										

$MMH-BeH_2$ (45)	Shift g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp. Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift g Isp 1000/Vac	A_e/A_t Vac.
Oxygen (27)	354	6763	5868	0.84	0.96	342	0.94		425	40.0
Hydrogen Peroxide (27)	349	6720	4968	0.92	1.06	340	4.00		416	40.0
Chlorine Trifluoride (27)	307	6055	6435	3.00	1.44	462	4.88		368	40.0
Nitrogen Tetroxide (27)	336	6413	5715	1.20	1.10	375	1.78		403	40.0
Chlorine Pentafluoride (27)	323	6350	7084	3.35	1.43	468	4.00		386	40.0

VII. THEORETICAL PERFORMANCE DATA

for

OXIDIZERS WITH VARIOUS FUELS

Oxygen		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine	(23)	313	6060	5680	0.923	1.07	335	0.923	297	361	43.7
Monomethylhydrazine	(24)	306			1.01	0.989					
Uns Dimethylhydrazine	(23)	310	5950	6050	1.70	0.977	304	1.86	291	335	35.9
50/50	(27)	312	6190	5860	1.27	1.02	319	1.41			
RP-1	(26)	300	5895	6165	2.60	1.02			286		
Hydrogen	(23)	391	7960	4530	3.55	0.264	159	9.00	387	446	31.1
Pentaborane	(23)	327	6230	7670	2.33	1.02	302	2.57	313	384	53.0
Diborane	(24)	349		6930	2.13	0.753					
MHF-1	(27)	301	5970	5640	0.818	1.11	336	0.835			
MHF-3	(27)	312	6140	5850	1.30	1.02	319	1.44			
MHF-5	(27)	307	6070	5780	1.02	1.07	330	1.06			
MAF-1	(27)	303	6020	5955	1.60	1.02	313	1.86			
Hybaline A4[a]	(27)	329	6450	6190	1.41	0.942	317	1.86			
Hybaline A4[b]	(27)	324	6390	6390	1.60	0.955	313	1.94		389	40.0
Hybaline A5[a]	(8)	341	6855	6760	1.50	0.94					
Hybaline A5[b]	(27)	326	6370	6480	1.63	0.94	310	1.86		388	40.0
[a] Heat of Formation = -16.5											
[b] Heat of Formation = -43											

Oxygen		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac.	A_e/A_t Vac.
Hybaline B3[a]	(8)	338		5785	1.38						
Hybaline B3[b]	(27)	330	6420	5985	1.70	0.90	301	2.03		392	40.0
Hydrogen/Be :: 50/50	(26)	458	9285	4660	0.884	0.23			453		
Hydrazine-Al-33	(27)	314	6200	6410	0.481	1.23	385	0.399			
Hydrazine-Al-43	(27)	310	6045	6760	0.470	1.29	402	0.428			
MMH-BeH_2-45	(27)	353	6765	5870	0.84	0.96	342	0.94		425	40.0
[a] Heat of Formation = -19.5											
[b] Heat of Formation = -50											

Fluorine		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine	(23)	363	6970	7980	2.23	1.31	478	2.45	333	395	31.8
Monomethyl Hydrazine	(26)	346	6825	7612	2.50	1.25			318		
Uns. Dimethyl Hydrazine	(23)	344	6500	7360	2.45	1.19	413	2.70	314	409	49.5
50/50	(27)	349	6840	7677	2.51	1.26	444	3.00			
RP-1	(26)	318	6153	6839	2.62	1.21			295		
Hydrogen	(23)	410	8120	6680	8.09	0.47	297	19.0	387	465	36.9
Ammonia	(24)	357		7718	3.35	1.15					
Pentaborane	(23)	360	6840	8730	4.56	1.20	454	9.00	328	430	49.1
Diborane	(24)	363			4.00	1.01					
MHF-1	(27)	348	7063	7731	1.70	1.32	461	1.90			
MHF-3	(27)	347	6855	7549	2.39	1.26	440	3.08			
MHF-5	(27)	352	7010	7785	2.23	1.31	463	2.57			
MAF-1	(27)	303	6022	5954	1.60	1.02	313	1.86			

IRFNA		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine	(24)	278		4948	1.50	1.28					
Monomethyl Hydrazine	(24)	278		5284	2.45	1.28					
Uns. Dimethyl Hydrazine	(24)	272		4955	3.17	1.27					
50/50	(27)	272	5420	5049	2.39	1.29					
Pentaborane	(24)	298		5815	3.35	1.17					
Hybaline A5[a]	(8)	319	6470	4699	1.00	1.01					
Hybaline A5[b]	(27)	297	5755	4025	0.786	0.938	355	4.13		357	40.0
Hybaline B3[c]	(8)	323		4465	0.59						
Hybaline B3[d]	(27)	305	6030	3935	0.59	0.845	349	4.26		364	40.0

[a] Heat of Formation = -16.5

[b] Heat of Formation = -43

[c] Heat of Formation = -19.5

[d] Heat of Formation = -50

Hydrogen Peroxide		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 100C/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine	(23)	286	5660	4800	2.03	1.26	363	2.12	279	337	39.7
Monomethyl Hydrazine	(26)	285	5665	4930	3.44	1.26			278		
Uns. Dimethyl Hydrazine	(23)	283	5520	4960	4.26	1.25	354	4.56	274	337	45.1
50/50	(27)	283	5710	4840	2.77	1.24	354	3.55			
Hydrogen	(23)	322	6570	3870	7.34	0.435	209	15.7	322	373	34.6
Ammonia	(27)	263	5325	3940	2.77	1.12	302	3.35			
Pentaborane	(23)	316	6210	5660	2.70	1.06	367	5.66	309	375	61.1
Diborane	(24)	334		4725	1.94	0.809					
MHF-1	(27)	278	5620	4795	1.67	1.29	361	1.99			
MHF-3	(27)	281	5665	4805	2.77	1.25	359	3.35			
MHF-5	(27)	284	5670	4875	2.28	1.28	365	2.70			
MAF-1	(27)	281	5560	4995	4.56	1.29	360	5.06			
Hybaline A4[a]	(27)	310		3780	1.00	0.994	366	4.88			
Hybaline A4[b]	(27)	305	6000	3755	1.06	1.01	369	5.90		362	40.0
Hybaline A5[a]	(8)	316	6435	4320	1.00	0.98					
Hybaline A5[b]	(27)	309	6035	3810	1.02	0.98					
[a] Heat of Formation = -16.5											
[b] Heat of Formation = -43											

Hydrogen Peroxide		Shift's Isp 1000/SL	C*	P_c psia	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hybaline B3[a]	(27)	324		3900	0.961	1.23	358	5.67			
Hybaline B3[b]	(27)	313	6135	3640	0.89	0.893	365	6.14		372	40.0
Hydrazine-Al-33	(27)	301	5965	5200	0.492	1.32	405	1.38			
Hydrazine-Al-43	(27)	304	5975	5545	0.408	1.40	425	0.428			
Hydrazine-Be-25	(27)	333	6380	5230	0.49	1.22	410	0.67		398	40.0
Hydrazine-Be-35	(27)	332	6380	5885	0.67	1.29	428	0.70		403	40.0
Hydrazine-Be-45	(27)	323	6205	6200	0.84	1.34	434	0.91		392	40.0
MMH-Be-45	(27)	323	6185	5925	1.04	1.28	415	1.13		391	40.0
Hydrazine-AlH_3-25	(27)	299	5975	5065	1.27	1.26	387	2.33		352	40.0
Hydrazine-AlH_3-35	(27)	307	6100	4580	0.49	1.21	394	2.33		360	40.0
Hydrazine-AlH_3-45	(27)	316	6255	4880	0.42	1.23	402	1.90		373	40.0
MMH-BeH_2-45	(27)	349	6720	4970	0.92	1.06	340	4.00		416	40.0
[a] Heat of Formation = -19.5											
[b] Heat of Formation = -50											

Chlorine Trifluoride		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 100:1/Vac	A_e/A_t Vac.
Hydrazine	(23)	293	5810	6530	2.70	1.48	436	2.70	278	337	32.8
Monomethyl Hydrazine	(24)	283		6105	2.84	1.42	282	3.17			
Una Dimethyl Hydrazine	(23)	280	5520	6370	3.00	1.37	385	3.17	269	323	40.9
50/50	(27)	283	5705	5884	2.57	1.44	414	3.65			
Hydrogen	(23)	318	6440	5670	11.5	0.610	289	27.6	299	364	30.9
Pentaborane	(23)	290	5550	7620	7.33	1.47	446	11.5	268	350	52.5
MHF-3	(27)	282		5769	2.39	1.42	411	3.76			
MHF-5	(27)	285		6226	2.51	1.51	431	3.00			
MAF-1	(27)	270	5380	5742	2.45	1.41	387	5.67			
Hybaline A4[a]	(27)	287	5630	6629	4.26	1.47					
Hybaline A4[b]	(27)	286	5545	6300	5.06	1.51	446	7.33		342	40.0
Hydrazine-Al-33	(27)	290		7220	2.51	1.65	477	2.57			
Hydrazine-Al-43	(27)	287	5710	7525	2.64	1.71	489	2.70			
Hydrazine-Be-25	(27)	304	6015	7160	2.85	1.61	496	3.76		360	40.0
Hydrazine-Be-35	(27)	303	5980	7390	3.08	1.65	507	4.13		364	40.0
Hydrazine-Be-45	(27)	305	6050	7590	3.26	1.69	517	3.55		365	40.0
[a] Heat of Formation = -16.5											
[b] Heat of Formation = -43											

Chlorine Trifluoride	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine-AlH_3-25 (27)	296	5950	6921	2.85	1.58	474	3.55		348	40.0
Hydrazine-AlH_3-35 (27)	295	5922	6984	2.77	1.59	482	3.76		349	40.0
Hydrazine-AlH_3-45 (27)	295	5880	7173	3.00	1.62	488	4.13		349	40.0
MMH-BeH_2-45 (27)	307	6055	6435	3.00	1.44	462	4.88		368	40.0

Nitrogen Tetroxide	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (23)	291	5610	5410	1.32	1.21	352	1.38	280	342	39.0
Monomethyl Hydrazine (24)	288		5645	1.49	1.19					
Uns. Dimethyl Hydrazine (23)	286	5520	5720	2.57	1.16	336	2.86	271	316	35.7
50/50 (26)	289	5740	5610	2.00	1.21			275		
RP-1 (27)	277	5420	4940	6.41	1.30	378	7.34	269	329	43.6
Hydrogen (23)	342	6980	4330	5.25	0.352	183	11.5	339	396	34.9
Ammonia (27)	262	5350	4495	2.03	1.06	283	2.23			
Pentaborane (23)	306	5890	7220	3.35	1.10	346	4.00	293	369	52.5
Diborane (24)	321		6615	3.16	0.925					
MHF-1 (27)	282	5680	5360	1.15	1.25	355	1.33			
MHF-3 (27)	288	5705	5571	2.03	1.21	351	2.23			
MHF-5 (27)	287	5725	5465	1.44	1.23	355	1.67			
MAF-1 (27)	281	5610	5740	2.64	1.23	346	3.00			
Hybaline A4[a] (27)	310		4315	0.724	0.948	358	3.17			
Hybaline A4[b] (27)	302	5890	4210	0.709	0.945	353	3.17		362	40.0
Hybaline A5[a] (27)	313		4385	0.667	0.917	354	3.26			
Hybaline A5[b] (27)	306	5955	4310	0.695	0.922	349	3.35		366	40.0

[a] Heat of Formation = -16.5, [b] Heat of Formation = -43

Nitrogen Tetroxide		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hybaline B3[a]	(27)	331		4660	0.614	1.16	347	3.65			
Hybaline B3[b]	(27)	316	6270	4375	0.64	0.843	341	4.0		375	40.0
Hydrazine-Al-33	(27)	304		5760	0.481	1.33	403	1.25			
Hydrazine-Al-43	(27)	299		6475	0.639	1.41	421	0.639			
Hydrazine-Be-25	(27)	325	6280	5985	0.67	1.25	405	0.74		392	40.0
Hydrazine-Be-35	(27)	315	6065	6390	0.85	1.31	411	0.91		381	40.0
Hydrazine-Be-45	(27)	304	5910	6905	1.11	1.36	414	1.17		370	40.0
Hydrazine-AlH_3-25	(27)	305	6085	5650	0.89	1.23	482	1.44		360	40.0
Hydrazine-AlH_3-35	(27)	312	6220	5200	0.49	1.21	391	1.27		367	40.0
Hydrazine-AlH_3-45	(27)	316	6240	5725	0.61	1.25	399	0.89		376	40.0
MMH-BeH_2-45	(27)	336	6415	5715	1.20	1.10	375	1.78		403	40.0
[a] Heat of Formation = -19.5											
[b] Heat of Formation = -50											

Perchloryl Fluoride	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (24)	295	5730	5779	1.47	1.22	295	1.56	279	358	39.4
Monomethyl Hydrazine (24)	291		5911	2.23	1.19	289	2.57			
Uns Dimethyl Hydrazine (24)	290	5590	6139	2.70	1.17	285	3.35	272	359	45.7
Hydrogen (24)	344	7060	4480	5.25	0.352	267	24.0	342	409	36.3
Pentaborane (24)	306	5870	7545	3.76	1.12	300	4.88	289	390	52.5

Oxygen Difluoride		Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine	(26)	339	6736	6689	1.54	1.27			317		
Monomethyl Hydrazine	(26)	343	6819	7202	2.32	1.24			319		
50/50	(26)	342	6795	7093	2.15	1.25			318		
RP-1	(26)	341	6838	7766	3.82	1.28			315		
Hydrogen	(26)	401	8188	5880	6.04	0.39			393		
Pentaborane	(26)	354	6969	8357	3.88	1.18			328		
Diborane	(26)	365	7209	7764	3.73	1.00			340		
Hybaline A4[a]	(27)	351	6937	7677	3.08	1.23	450	5.90			
Hybaline A4[b]	(27)	349	6900	7720	3.26	1.24	442	4.56		415	40.0

[a] Heat of Formation = -16.5

[b] Heat of Formation = -43

Tetrafluorohydrazine	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (24)	334		7583	3.26	1.44					
Monomethyl Hydrazine (24)	327		7583	3.35	1.37					
RP-1 (26)	297	5810	6400	3.60	1.34			275		
Pentaborane (24)	334		8177	7.32	1.38					

Chlorine Pentafluoride	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (27)	311	6305	6849	2.51	1.46	454	2.57			
Monomethyl Hydrazine (27)	298	5948	6228	2.57	1.39	421	3.55			
Uns. Dimethyl Hydrazine (27)	292	5835	6093	2.45	1.31	397	4.56			
50/50 (27)	300	5971	5334	2.51	1.40	426	3.65			
RP-1 (27)	269	5370	5936	2.77	1.35	387	6.69			
MHF-1 (27)	295	6125	6867	2.39	1.50	452	2.51			
MHF-3 (27)	299		6228	2.51	1.39	427	3.26			
MHF-5 (27)	303		6696	2.51	1.46	442	2.77			
MAF-1 (27)	287	5715	6102	2.45	1.37	397	3.35			
Hybaline A4[a] (27)	304	5995	7209	4.56	1.44	452	7.0			
Hybaline A4[b] (27)	302	5945	7065	4.41	1.43	447	7.33		361	40.0
Hydrazine-Al-33 (27)	306	6105	7675	2.51	1.60	491	2.51			
Hydrazine-Al-43 (27)	303	5990	7900	2.57	1.65	499	2.51			
[a] Heat of Formation = -16.5										
[b] Heat of Formation = -43										

Chlorine Pentafluoride		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 100)/Vac	A_e/A_t Vac.
Hydrazine-Be-25	(27)	320	6310	7055	1.94	1.50	500	4.00		382	40.0
Hydrazine-Be-35	(27)	317	6105	7898	3.00	1.60	515	4.13		381	40.0
Hydrazine-Be-45	(27)	317	6250	8100	3.44	1.64	523	4.00		381	40.0
Hydrazine-AlH_3-25	(27)	313	6280	7227	2.57	1.52	480	3.17		369	40.0
Hydrazine-AlH_3-35	(27)	313	6240	7668	3.00	1.56	492	3.55		364	40.0
Hydrazine-AlH_3-45	(27)	312	6235	7650	3.26	1.59	498	3.76		365	40.0
MMH-BeH_2-45	(27)	323	6350	7084	3.35	1.43	468	4.00		386	40.0

Ozone	Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (27)	334	6605	6039	0.85	1.18	395	0.98			
RP-1 (27)	329		6606	2.23	1.16	390	3.08			
Hydrogen (27)	427	8653	5427	3.76	0.283					

Moxy 2	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (27)	315	6435	6975	3.08	1.23	392	3.55			
Monomethyl Hydrazine (27)	305	6090	6566	3.44	1.19	368	4.56			
Uns. Dimethyl Hydrazine (27)	301	5920	6494	3.65	1.16	355	5.06			
50/50 (27)	307	6131	6726	3.44	1.20	374	4.71			
RP-1 (27)	287	5625	6345	4.56	1.19	344	5.45			
Hydrogen (27)	343	7128	5329	9.00	0.48					
MHF-1 (27)	310	6342	6946	2.45	1.25	387	2.57			
MHF-3 (27)	306	6104	6573	3.26	1.20	373	4.56			
MHF-5 (27)	308	6245	6823	2.92	1.23	382	3.26			
MAF-1 (27)	294	5840	6258	3.17	1.18	353	4.71			
Hybaline A4 (27)	312	6185	7272	5.90	1.20					
Hydrazine-A1-33 (27)	313	6285	7786	3.08	1.32	414	3.08			

Compound "T" - N_2O_4*	Shift's Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A_e/A_t Vac.
Hydrazine (27)	326	6620	7425	3.55	1.42	467	4.26		379	40.0

* ½ mole of N_2O_4 per mole Compound "T"

$O_2/F_2/O_3$ Mixtures		Shift'g Isp 1000/SL	C*	T_c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift'g Isp 1000/Vac	A_e/A_t Vac.
Hydrazine/50:10:40	(27)	325	6420	5943	0.961	1.14					
Hydrazine/40:10:50	(27)	327	6452	5985	0.961	1.15					
Hydrazine/30:10:60	(27)	329	6496	6012	0.942	1.17					
Hydrazine/20:10:70	(27)	331	6530	6057	0.942	1.18					
RP-1/50:10:40	(27)	318	6230	6543	2.57	1.11					
RP-1/40:10:50	(27)	321	6300	6570	2.51	1.14					
RP-1/30:10:60	(27)	323	6360	6597	2.45	1.16					
RP-1/20:10:70	(27)	326	6430	6624	2.39	1.17					
Hydrogen/50:10:40	(27)	408	8308	5189	4.0	0.292					
Hydrogen/40:10:50	(27)	412	8375	5261	4.0	0.294					
Hydrogen/30:10:60	(27)	415	8440	5329	4.0	0.295					
Hydrogen/20:10:70	(27)	419	8503	5396	4.0	0.297					

VIII. LIQUID PROPELLANT REFERENCES

LIQUID PROPELLANT REFERENCES

*1. "Liquid Propellant Handbook," Battelle Memorial Institute, 1955-1957. (Confidential)

*2. JANAF Thermochemical Data, "JANAF Heat of Formation of Propellant Ingredients (U)," 1963-1964. (Confidential)

*3. AFRPL Computer Data File.

4. "Diborane, Space Storable Fuel," Callery Chemical Co., January 1962.

5. "Design Handbook for Oxygen Difluoride," Donald F. Sekets, ATD-TDR-63-1084, Contract AF 04(611)-8400, Thiokol Chemical Co., Reaction Motors Division. (Confidential)

*6. "Hybaline Liquid Rocket Fuels - Technical Information," Union Carbide Corporation, 1 November 1964. (Confidential)

7. "The Handling and Storage of Liquid Propellants," AFM 160-39, 1 April 1964.

*8. "Research and Development of Metal Hydride Organic Nitrogen Complexes," Final Report, 3 Volumes, Union Carbide Corporation, 1 November 1964. (Confidential)

9. "Handbook of Astronautical Engineering," Heinz Hermann Koelle, McGraw-Hill Book Co., 1961.

10. "Storable Liquid Propellants," 2nd Ed., Report No. LRP 198, Aerojet-General Corp., June 1962.

11. "Storable Liquid Propellants," Revision A, Aerojet-General Corporation, October 1960.

12. "Liquid Propellant Manual," Liquid Propellant Information Agency, 1961. (Confidential)

*13. "Solid Rocket Propellant Research and Development (U)," Annual Report, Jan-Dec 1962, Contract NOrd 18728, American Cyanamid Co. (Confidential)

*14. "Solid Rocket Propellant Research and Development (U)," Progress Report No. 16, April-June 1964, Contract NOrd 18728, American Cyanamid Co. (Confidential)

15. "Chemical Safety Data Sheet SD-84 - Boron Hydrides," Manufacturing Chemists Association, 1961.

*Classified information has been extracted from documents listed under References marked with an asterisk.

16. "Pentaborane," Technical Bulletin CT-1300, Production Information, Callery Chemical Co., 1 October 1961.

*17. "Chemical Research as Related to Advanced Solid Propellants (U)," Report No. 19 (Final Report), Jan to Dec 1963, Contract NOrd 18688, Minnesota Mining and Manufacturing Co. (Confidential)

18. "Tetrafluorohydrazine," Liquid Propellant Information Agency Unit, 6 July 1962.

*19. "Preparation and Characterization of a New High-Energy Oxidizer (U)," Final Report, Contract AF 04(611)-9563, Rocketdyne, January 1965. (Confidential)

*20. "Evaluation of a High Energy Liquid Propellant Rocket Engine Oxidizer and a Pilot Production of Same (U)," Final Report, Contract AF 04(611)-8182, Minnesota Mining and Manufacturing Co, April 1965. (Confidential)

*21. "Interhalogen Oxidizers and Hydrazine Fuels for Packaged Liquid Power Plants," TPR 120-64, Thiokol Chemical Co., Reaction Motors Division, January 1964. (Confidential)

*22. "Packaged Liquid Propulsion Symposium," CPIA Publication No. 13, Bureau of Naval Weapons, March 1963. (Confidential)

23. "Thermodynamics of Rocket Propulsion and Theoretical Evaluation of Some Prototype Propellant Combinations," Thomas O. Dobbins, WADC TR-59-757, December 1959.

24. "Propellant Performance Data," Callery Chemical Co., 1961.

25. "Theoretical Liquid Propellant Performance Calculations (U)," Donald G. Nyberg, NAVWEPS report 8588, NOTS TR 3597, U.S. Naval Ordnance Test Station, October 1964. (Confidential)

26. "Theoretical Performance of Rocket Propellant Combinations," Publication 573-A-2 Rev. 3-64, Rocketdyne.

*27. AFRPL (RPCL) Computer program,

*28. "Proceedings of the Metallized Gelled Propellants Conference," Air Force Rocket Propulsion Laboratory, 10-12 June 1963. (Confidential)

*29. "2nd Metallized Gelled Propellants Conference," Air Force Rocket Propulsion Laboratory, 26-28 August 1964, CPIA Publication No. 64, November 1964. (Confidential)

*30. "Investigation of a High-Energy Monopropellant," Annual Summary Report, Rocket Research Corp, AFRPL-TR-65-18, April 1965. (Confidential)

*Classified information has been extracted from documents listed under References marked with an asterisk.

IX. SOLID PROPELLANT PROPERTIES

FUELS

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
Al (s)	Aluminum	LM-1	2.7	(1)	0.0	(1)
AlH_3 (s) (Form 1451)	Aluminum Hydride	LMH-1	1.4	(7)	-2.2 ± 1 -2.77± .1	(7)
Be (s)	Beryllium	LM-2	1.85	(1)	0	(1)
BeH_2 (s)	Beryllium Hydride	LMH-2	0.38	(2)	-4.5	(2)
$Be_{8.6542}H_{17.6277}C_{0.3522}$ (93%)			.66	(12)	-53.6	(12)
$Be_{1.00}H_{2.0356}O_{0.008}C_{0.0278}$					-5.576	(12)
B (s)	Boron		2.32	(1)	0.0	(1)
$B_{10}H_{14}$ (s)			0.94	(1)	-15.8	(1)
$C_{10}H_{20}$ (l)	Decaborane		0.804	(1)	-173.3	(1)
$C_{9.657}H_{18.87}$ (l)		UP-4	0.77	(1)	-54.8	(1)
Li (s)	Lithium		0.534	(1)	0.0	(1)
LiH (s)	Lithium Hydride		0.820	(1)	-21.6	(1)
$LiAlH_4$ (s)	Lithium Aluminum Hydride		0.93	(1)	-24.1 -26.63±.311	(1) (21)
$LiBH_4$ (s)	Lithium Borohydride		0.66	(1)	-46.44	(1)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
Mg (s)	Magnesium		1.74	(1)	0.0	(1)
MgH_2 (s)	Magnesium Hydride		1.45	(1)	-17	(1)
Na	Sodium		0.97	(1)	0.0	(1)
NaH	Sodium Hydride		---		-13.7	(2)
Pb (s)	Lead		11.337	(1)	0.0	(1)
S (s)	Sulphur		2.046	(1)	0.0	(1)
Si (s)	Silicon		2.4	(1)	0.0	(1)
SiH_4 (l)	Silicon Hydride		0.68 @ 162	(1)	6.4 @ 162	(1)
Ti (s)	Titanium		4.5	(1)	0.0	(1)
Zr	Zirconium		6.4	(1)	0.0	(1)
$B_{10}H_{10}C_2H_2$	Carborane		---		-27.6	(4)
$(CH_3)_4NB_3H_8$	Tetramethyl ammonium triborohydride		---		-22	(6)
$Mg(AlH_4)_2$	Magnesium Aluminum Hydride		---		-31.5±6	(7)
$LiAlH_4 . 5AlH_3$			---		-44	(8)
$LiAlH_4 . 10AlH_3$			---		-64	(8)
ZrSi			---		-18	(8)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$ZrSi_2$			---		-12	(8)
$C_{17}H_{20}ON_2$	Ethyl Centralite		---		-34.2	(10)
$C_6H_8ON_2$	Adiponitrile		---		+26.3	(10)
$Al(B_3H_8)_3$	Aluminum Triborohydride		0.5	(11)	-75	(11)
$Al(BH_4)_3.CH_2O$	Aluminum Borohydride Polymethylene Oxide		1.80	(11)	-132	(11)
$Al(BH_4)_3.2C_2H_4O$	Aluminum Borohydride: Polyethylene Oxide		0.71	(11)	-177.4	(11)
$Be(BH_4)_2$	Beryllium Borohydride		---		-25.8	(7)
$Al(BH_4)_3$	Aluminum Borohydride		0.57	(5)	+2.5	(7)
$Zr(BH_4)_4.CH_3NH_2$			---		-34.2	(13)
LiAl			---		-15	(8)
Li_2BeH_4			0.703	(12)	-79.9	(12)
$LiBeH_3$			---		-42.2	(12)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_{10}H_{22}$	Isodecane		0.728	(20)	-73.1	(20)
$PbC_{36}H_{70}O_4$	Lead Stearate	PbSt	0.9	(20)	-424	(20)
$(N_2H_5)_2B_{10}H_{10}$	Dihydrazinium Perhydrodecaborate	H_2D	---		-48.3±4.7	(6)
$(CH_3)_4NB_3H_8$	Tetramethyl Ammonium Hydrotriborate	QMB3	---		-40. ±1.5	(5)
$(C_2H_5)_4NB_3H_8$	Tetraethyl Ammonium Hydrotriborate	QEB3	---		-59.0±3.0	(5)
AlH_3	Olane 58		---		-4.6±1.6	(21)
AlH_3	Dowane 1451		---		-2.53±1.6	(21)
Li_3AlH_6			---		-79.4 ±3.4	(21)
NH_4CN	Ammonium Cyanide		0.79	(14)	-0.7	(14)

CONFIDENTIAL

OXIDIZERS

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formulation	(Ref)
NF_3 (l)	Nitrogen Trifluoride		1.532@144°C	(1)	-32@144°C	(1)
NH_4NO_3 (s)	Ammonium Nitrate	AN	1.725	(1)	-87.27	(1)
NH_4ClO_4 (s)	Ammonium Perchlorate	AP	1.96	(1)	-70.7	(20)
NO_2ClO_4 (s)	Nitronium Perchlorate	NP	2.22	(1)	8.0	(1)
$N_2H_5NO_3$ (s)	Hydrazinium Nitrate		1.685	(1)	-59	(1)
$LiClO_4$ (s)	Lithium Perchlorate		2.43	(1)	-92.0 -90.88	(1) (20)
$F_{1.5836}O_{0.4197}$ (g)	Air		---		0.0	(1)
NF_2OH	Hydroxylamine		---		-25.5	(2)
NH_4NO_2	Ammonium Nitrite		---		-63.1	(2)
$NH_3OH\ NO_3$	Hydroxylammonium Nitrate		---		-86.3	(2)
$CF(NO_2)_3$		D-11	1.502	(3)	-37.3	(3)
$C_2F_2(NO_2)_4$		D-112	1.702	(3)	-90.5	(3)
$N_2H_5C(NO_2)_3$		HNF	1.85	(4)	-17	(4)
$N_2H_5ClO_4$ (s)	Hydrazinium Perchlorate		---		-40.4	(1)

Formula	Names	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_2(NO_2)_6$	Hexanitro Ethane	HNE	1.81	(4)	+24.1	(4)
$(LiClO_4)_{.6}NO_2ClO_4$			2.29	(4)	-50	(4)
$(NO_2)_3Al(ClO_4)_6$			2.35	(4)	-120	(4)
$[(NO_2)_3CCH_2]_2\ NNO_2$		BTNEN	1.96	(4)	+6	(4)
$C_3H_5O_9N_3$	Nitroglycerine	NG	1.60	(4)	-89.1 -82 -90.75	(20) (4) (7)
$HC(NO_2)_3$	Nitroform		1.60	(4)	-18.6	(4)
$C(NO_2)_4$	Tetranitro Methane	TNM	1.65 1.64	(4) (3)	+8.8 +10.3	(4) (3)
$C_5H_9O_{10}N_3$	"Petrin"		1.60	(4)	-133	(4)
$C_4H_8N_8O_8$	Cyclotetramethylene Tetranitramine	HMX	1.90	(4)	-17.92 +11	(4) (7)(8)
$C_2H_4(NF_2)_2$			---		-46.6 -38	(4) (5)
$CH_3CH(NF_2)CH_2(NF_2)$			---		-40.1	(5)
$CH_2(NF_2)CH(NF_2)CH_2(NF_2)$			1.503	(4)	-71.8	(4)
$CH_3CH(NF_2)CH(NF_2)CH_3$ (l) (g)			1.226	(4)	-67.6 -58.8	(4) (4)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_4H_6(NF_2)_4$			1.54	(4)	-93.4	(4)
$C_4H_5(NF_2)_5$			---		-109.4	(4)
$C_4H_4(NF_2)_4O$	Tetrakis (DA) Tetrahydrofuran		1.604	(4)	-108.0	(4)
$C_4H_3(NF_2)_5O$	Pentakis (DA) Tetrahydrofuran		1.65	(4)	-124.0	(4)
$C_4H_4(NF_2)_6$			---		-125.4	(4)
$C_4H_2(NF_2)_6O$	Hexakis (DA) Tetrahydrofuran		---		-140.6	(4)
$C_4(NF_2)_8O$	Octakis (DA) Tetrahydrofuran		---		-172	(4)
	Hexakis (DA) Bz		1.82	(4)	-22.2	(4)
$C_6H_7(NF_2)_5$	Pentakis (DA) Cyclohexane		1.746	(4)	-111.5	(4)
$C_6H_6(NF_2)_6$	Hexakis (DA) Cyclohexane		1.75	(4)	-127.2	(4)
$C_6(NF_2)_{12}$	Tetrakis (DA) Tetrahydrofuryl urea		1.97	(4)	-221.29	(4)
$O=C[NHC_4H_3(NF_2)_4O]$			---		-347.15	(4)

CONFIDENTIAL

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$[C_5H_4(NF_2)_5]_2$			---		-161	(4)
NF_3OHClO_4	Hydroxyl Ammonium Perchlorate		---		-68	(8)
$CN_2H_6C(NO_2)_3$	Guanidine Nitroform		---		-48	(8)
HNF_2			1.42@0°C	(9)	-10	(9)
O_2F_2			1.95	(9)	+ 6.6	(9)
$C_2H_2N_4O_9$		TNEN	---		-22.6	(10)
$C_5H_8N_6F_8O$		DEI-UREA			-44.0	(10)
$C_5H_7N_3O_2F_4$		PVA-DEI	1.1	(20)	-124 -93.3	(20) (10)
$C_4H_6N_4F_8$		TDB	---		-93.3	(10)
CN_3F_7		R	1.8	(11)	-75±5 -43.3±1	(11) (7)
$CH_6N_6 \cdot HClO_4$	Triamino Guanidinium Perchlorate		1.55	(11)	15	(11)
$NO_2B(ClO_4)_4$			---		-83±5	(5)
$NH_4B(ClO_4)_4$			---		-145 to -150	(5)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_4H_4N_4F_8O$ (l)	Tetrakis Difluoramino Tetrahydrofuran		---		-82	(8)
CN_3F_5 (g)	Perfluoroguanidine	PFG	---		+34±10	(7)
$C_4H_6O_6N_4F_4$	3,4 bis (DA)-1,2 butanediol dinitrate		1.59	(10)	-82	(10)
$C_2H_4[NH_3C(NO_2)_3]_2$	Ethylene Diamine Dinitroform		---		-68	(8)
$HNC[NH_3C(NO_2)_3]_2$	Guanidine Dinitroform		---		-76	(8)
$C_6H_{16}N_4[C(NO_2)_3]_4$	Hexamethylene Tetramine Tetranitroform		---		-71	(8)
$N_2H_4[C(NO_2)_3]_2$	Hydrazine Dinitroform		---		-31	(8)
$HONH_3C(NO_2)_3$	Hydroxylamine Nitroform		---		-44	(8)
$N_2H_5(ClO_4)_2$	Hydrazine Diperchlorate		---		-72	(8)
$(NO_3)N_2H_5C(NO_2)_3$	Hydrazine Nitroform Nitrate		---		-69	(8)
$CH_3NH_3C(NO_2)_3$	Methylamine Nitroform		---		-50	(8)
$\{HC[N_2H_4C(NO_2)_3]\}_n$	HMH Nitroform		---		-21	(8)

CONFIDENTIAL

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$NH_2NC[NHNH_3C(NO_2)_3]_2$	TAG Dinitroform		---		+6	(8)
$HClO_4$ (l)	Perchloric Acid		---		- 11.1	(2)
$NH_2NC(NHNH_2)NHNH_3C(NO_2)_3$	TAG Nitroform		---		+27	(8)
N_2O_5	Dinitrogen Pentoxide		---		-10.6	(14)
CH_3NF_2 (g)			---		-20.5±2.0	(7)
$CF_2(OF)_2$ (g)			---		-130 ± 3	(7)
$C_3H_3H_6(NO_2)_3$		RDX	1.816	(20)	16.1	(20)
$C_5H_9O_9N_3$		TMETN	1.488	(20)	-105	(20)
$CF_2(OF)_2$ (g)			---		-130.7± 1	(7)
$CF_2(NF_2)_2$ (g)			---		-103.7± 1	(7)
$C_2F_{11}N_5$ (l)		$F_{11}BG$	---		-83.5 ± 2.9	(7)
$FClO_4$ (g)	Fluorine Perchlorate		---		+37.6± 9	(17)
FNO_3 (g)	Fluorine Nitrate		---		+2.5 ± .6	(17)
NO_2F			---		-25.8	(17)
$C_4H_6N_4O_{11}$		NIBNG	1.65	(18)	-86.4	(18)
$X_3COCH_2CH_2OCX_3$		EGA	---		-73.7	(10)
$X_3COCH_2CX_2CH_2OCX_3$		FAGD	---		-91.1	(10)

CONFIDENTIAL

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$X_3CNHCO-NHNHCONHCX_3$		BTBU	---		-86.5	(10)
$X_3CNHCONHCX_3$		HDM-UREA	---		-46.9	(10)
$C_6H_{11}O_3N_9$	Hexanetriol Trinitrate	HTT	1.405	(20)	-124.6	(20)
$CH_4O_2N_4$	Nitroguanidine	HBNQ	1.69	(20)	-21.6	(20)
$C_{12}H_{10}O_2N_2$	Nitrodiphenylamine	2-NDPA	1.366	(20)	+17.82	(20)
C_3H_3N	Polyacrylonitrile		1.13	(20)	+28.27	(20)
C_3H_5ON	Polyacrylamide		1.122	(20)	-67	(20)
$C_{.835}H_{.731}O_{5.373}N_{.856}Cl_{1.0}$	NP - Chlorostyrene		2.0	(20)	+ 6.82	(20)
$C_{1.001}H_{.779}O_{5.333}N_{1.0}Cl_{.889}$	NP - Cyanostyrene		2.12	(20)	+12.06	(20)
$C_{.683}H_{.512}O_{5.487}N_{.915}Cl_{1.085}$	NP - Dichloro-styrene		2.06	(20)	+7.43	(20)
$C_{1.075}H_{1.075}O_{5.194}N_{.866}Cl_{.866}$	NP - Styrene		1.93	(20)	48.13	(20)
$C_2H_4N_6O_8$	NNNN'TetraNitro Ethylene Diamine	TNEDA	1.75		+55.9	(9)
N_2O_5 (g)			1.63	(14)	-10.0	(14)

CONFIDENTIAL

BINDERS

Formula	Names	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
CH_2 (s)	Polyethylene	PE	.92	(1)	-6.5	(1)
C_2F_4 (s)	Teflon		2.1	(1)	-193.5	(1)
$C_{5.3614}H_{9.8716}O_{1.4016}N_{0.119}$		POLYU	1.01	(1)	-75.24	(1)
$C_{5.117}H_{9.586}O_{1.684}N_{0.138}$		POLYU			-82.8	(20)
$C_{11}F_{14}H_8$ (s)		VITON	1.85	(1)	-726.7	(1)
$C_{2.53}H_{4.10}N_{1.64}O_{2.66}$	Nitro Polyurethane	NPU	1.5	(4)	-16.7	(4)
$(C_2N_2)_x$	Paracyanogen		---		+55	(4)
$CHNO_2$			1.6	(4)	0.0	(4)
$(C_6H_{7.55}O_{9.9}N_{2.55})_x$	Nitrocellulose	NC	1.66	(4)	-170.2	(14)
$[C_4H_6(NF_2)_2]_x$	Difluoramino Butadiene	LBPB	1.45	(4)	-54.4	(4)
$C_4E_6H_{13}F_{2.6}$			1.39	(20)	-35.3	(20)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_2H_3OOCC_4H_3(NF_2)_4O$			---		-187	(4)
$C_2H_3OOCC_4H(NF_2)_6O$			---		-216	(4)
$(CHNF_2)_x$			1.65	(4)	-21.45	(4)
$C_{11}H_8F_{14}$	(Fluorel Polymer)		1.80	(4)	-760.4	(4)
$(CH_2CH_2NNH_2)_x$		PEH	---		+4	(6)
CN_3F_5	Polyperfluoro-guanidine		1.93	(11)	-24.5 (est)	(11)
CN_2F_4	Polyperfluoro-formamidine		1.87	(11)	-62.6 (est)	(11)
$C_3N_6F_{12}$	Perfluoromelamine		1.6	(11)	-168.84 (est)	(11)
C_3F_7NO	(C_2F_4-CF_3NO Copolymer)		1.82	(11)	-351 (est)	(11)
$C_{1.132}H_{5.952}N_{5.718}$	Polytriaminoguanidine Azide	Poly Taz II	---		+65.3	(7)
$C_{6.9535}H_{10.3873}O_{.1614}N_{.0042}P_{.0014}S_{.0158}$		PPAA	0.927	(20)	+17.68	(20)

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_{10}H_{16}O_5$		HX-730	1.4	(20)	-45.24	(20)
$C_{1.71}H_{2.445}O_{3.78}N_{1.178}$		DB	1.4	(20)	-45.24	(20)
$C_{73.99}H_{134.41}O_{24.48}N_{2.43}$		E107	1.05	(20)	-1369.1	(20)
$C_{119.7}H_{215.4}O_{39}N_4$		ESTANE 5830101	1.0	(20)	-2194.8	(20)
$C_9H_{11}O_{10}N_5F_4$	Nitrocellulose Difluoramino Ethyl Isocyanate	NCDEI	1.1	(20)	-274	(20)
$C_{2.341}H_{3.75}O_{3.401}N_{0.976}$		NCTMETN	1.48	(20)	-52.62	(20)
$C_{2.778}H_{4.622}O_{2.14}N_{1.581}$	(Nitro-polymer)		1.4	(20)	-7.95	(20)
$C_{7.582}H_{12.372}O_{4.093}N_{0.6046}$	Polyglycol dipate-Oxamide 511	PGAO	1.243	(20)	-207.7	(20)
C_2F_3Cl	KEL-F		---		-51.4	(20)
$C_{1.808}H_{2.686}O_{3.707}N_{1.100}$		DB(VCP)	1.57	(23)	-50.65(calc)	(23)
$C_{2.137}H_{3.441}O_{3.482}N_{1.087}$		DB(BARC)	1.49	(23)	-46 (calc)	(23)

CONFIDENTIAL

ADDITIVES

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
He (1)	Helium		0.1251	(1)	-1.48	(1)
$N_2H_4(BH_3)_2$	Hydrazine bis-Borane	HBB	0.86	(4)	-30	(4)
$N_2H_2(BH_2)_2$		HoBB	1.15	(4)	-49	(4)
$N_2H_4(B_3H_2)$	Hydrazine Triborohydride		--		-10	(4)
$N_2H_4(BH_3)$			.955	(4)	-10	(4)
$B_{10}H_{14}(NH_3)_2$	Dekazene		1.06	(16)	-104	(4)
$B_{10}H_{12}(NH_3)_2$					-66.6	(16)
$(CH_3)_2N_2(BH_2)_2$			---		-49	(4)
$(CH_9N_6)_2B_{10}H_{10}$	TAG Decaborane		1.54	(4)	+60	(4)
$(N_2H_5)_2B_{10}H_{12}\cdot N_2H_4$		H_3D	---		-22	(6)
$CH_9N_6B_3H_8$	TAG Triboro-hydride		---		+47.9	(6)
$(CH_3)_4NB_3H_8$	Tetra Methyl Ammonium Triboro-hydride		---		-33.6	(6)

CONFIDENTIAL

Formula	Name	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
$C_6H_6O_2$	Resorcinol	RES	1.27	(15)	-87.57	(15)
$C_2H_6O_2$	Ethylene Glycol	EG	1.115	(20)	-108.5	(20)
$C_4H_{10}O_2$	1,4 Butanediol		1.02	(20)	-120	(20)
$C_{15}H_{26}O_6$	Tibutyrin	TB	1.032	(20)	-357.8	(20)
$C_6H_{15}O_3N$	Triethanolamine	TEA	1.124	(20)	-158.9	(20)
CN_3O_6Cl	Chloronitroform	CLNF	1.7	(20)	-50.0	(20)
$C_{109}H_{149}O_{74}$	Cellulose Acetate		1.4	(20)	-2582.2	(20)
$C_5H_{10}O_6N_2$	1,5 Dinitroxypentane	1,5 DNP	0.9	(20)	-78.34	(20
$C_5H_{10}O_6N_2$	2,4 Dinitroxypentane	2,4 DNP	0.9	(20)	-85.13	(20)
$C_3H_6O_6N_2$	1,2 Dinitroxypropane	1,2 DNP	1.2	(20)	-70.56	(20)
$C_{12}H_{14}O_4$	Diethylphthalate	DEP	1.123	(20)	-178.6	(20)
$C_{13}H_{34}O_4$	Di-n-Butyl Debacate	DBS	1.0	(20)	-285.1	(20)
$C_2H_8O_4N_2$	Ammonium Oxalate		1.501	(20)	-286.72	(20)
CH_3ON	Formamide		1.139	(20)	-62.4	(20)
C_3H_5ON		PAM	---		-65	(6)
$NH_4B_3H_8$			---		-96.5	(24)

CONFIDENTIAL

X. SOLID PROPELLANT THEORETICAL PERFORMANCE

(listed by fuel)

ALUMINUM

20% PE / 65% NP / 15% Al (25)

Isp	T_c	Density	C*	Vac Isp
281 sec	3870°K	1.772 g/cc	5526 ft/sec	355 sec

20% PE / 65% HAP / 15% Al (25)

Isp	T_c	Density	C*	Vac Isp
263 sec	2930°K	1.699 g/cc	5237 ft/sec	321 sec

15% NC / 30% TMETN / 1% AN / 44% INFO 635 / 10% Al (25)

Isp	T_c	Density	C*
279 sec	3640°K	1.79 g/cc	5510 ft/sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

BERYLLIUM

25% TMETN / 4% DEGDN / 9.5% PNC / 1.5% TDI / 27.73% AP / 12.27% Be / 20% TAZ (25)

Isp	T_c	Density	C*
287 sec	3552°K	1.691 g/cc	5631 ft/sec

23.12% TMETN / 2.78% DEGDN / 8.79% NC / 1.85% TDI / 0.46% EC / 29.11% AP / 11.89% Be / 22% THA (25)

Isp	T_c	Density	C*	Vac Isp
297 sec	3485°K	1.628 g/cc	5650 ft/sec	332 sec

13% NC / 37% TMETN / 33% AP / 17% Be (8)

Isp	T_c	Density
280 sec	3965°K	1.66 g/cc

9.95% NC / 14.93% TMETN / 16.41% DEGDN / 1.0% TDI / 26.16% AP / 11.55% Be / 19.9% TAZ (8)

Isp	T_c	Density
9 sec	3481°K	1.62 g/cc

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

BORON

P-BEP/TVOPA :: 1/1
25% Binder / 50% BTU / 20% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
297 sec	4255°K	1.828 g/cc	5940 ft/sec	366 sec

P-BEP/TMETN :: 1/1
25% Binder / 60% BTU / 10% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
299 sec	4340°K	1.766 g/cc	5981 ft/sec	369 sec

35% P-BEP / 40% BTU / 20% NP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
300 sec	4408°K	1.807 g/cc	5951 ft/sec	374 sec

70% P-BEP / 25% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
279 sec	3409°K	1.742 g/cc	5568 ft/sec	344 sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

LITHIUM

28.7% P-BEP / 14.4% NP / 11.7% Li / 45.2% BTU (25)

Isp	T_c	Density
308 sec	4561°K	1.40 g/cc

POLYU

75% NP (5% Coat) / 25% POLYU (25)

Isp	T_c	C*
270 sec	3518°K	5182 ft/sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

LMH-1

20% PE / 62.5% NP / 17.5% LMH-1 (25)

Isp	T_c	Density	C*	Vac Isp
292 sec	3527°K	1.616 g/cc	5781 ft/sec	361 sec

20% PE / 55% HAP / 25% LMH-1 (25)

Isp	T_c	Density	Vac Isp
272 sec	2423°K	1.53 g/cc	343 sec

8% NC / 24% TEGDN / 50% INFO-635 / 18% LMH-1 (25)

Isp	T_c	Density	C*	Vac Isp
280 sec	3156°K	1.62 g/cc	5545 ft/sec	410 sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

LMH-2

20% P-BEP / 55% AP / 25% LMH-2 (25)

Isp	T_c	Density	C*	Vac Isp
321 sec	3290°K	1.28 g/cc	6168 ft/sec	413 sec

10.8% NC / 3.9% DEGDN / 35.1% NIBTN / 35.2% AP / 15% LMH-2 (18)

Isp	T_c	Density
301 sec	3588°K	1.27 g/cc

11.4& NC / 23% TMETN / 22% Plasticizer / 27% AP / 3.2% Be metal / 13.5% LMH-2 (amorphous) (8)

Isp	T_c	Density
304 sec	3453°K	1.36 g/cc

48% TMETN / 2.3% PMMA / 29.6% NP (5% coat) / 1.1% Be / 19% Beane (8)

Isp	T_c	Density
317 sec	3588°K	1.27 g/cc

33% P-BEP / 43% NP / 24% LMH-2 (Density 0.82 g/cc) (25)

Isp	T_c	Density
325 sec	3667°K	1.49 g/cc

63.5% Double [illegible] Binder* / 17% AP / 19.5% LMH-2 (25)

Isp	T_c	Density
311 sec	334[illegible]°K	1.37 g/cc

[illegible] NC / 62% NG / [illegible]% TA / 2% NDPA / [illegible]% Res.

NOTE: All [illegible]evel specif[illegible] impulse values are at 1000 psia chamber pressure e[illegible]ed to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

XI. SOLID PROPELLANT THEORETICAL PERFORMANCE

(listed by oxidizer)

AMMONIUM PERCHLORATE

25% TMETN / 4% DEGDN / 9.5% PNC / 1.5% TDI / 27.73% AP / 12.27% BE / 20% TAZ (25)

Isp	T_c	Density	C*
287 sec	3552°K	1.69 g/cc	5631 ft/sec

23.12% TMETN / 2.78% DEGDN / 8.79% NC / 1.85% TDI / 0.46% EC / 29.11% AP / 11.89% Be / 22% THA (25)

Isp	T_c	Density	C*	Vac Isp
293 sec	3485°K	1.628 g/cc	5650 ft/sec	332 sec

13% NC / 37% TMETN / 33% AP / 17% Be (8)

Isp	T_c	Density
280 sec	3965°K	1.66 g/cc

9.95% NC / 14.93% TMETN / 16.41% DEGDN / 1.0% TDI / 26.26% AP / 11.55% Be / 19.9% TAZ (8)

Isp	T_c	Density
289 sec	3481°K	1.62 g/cc

20% P-BEP / 55% AP / 25% LMH-2 (25)

Isp	T_c	Density	C*	Vac Isp
321 sec	3290°K	1.279 g/cc	6168 ft/sec	413 sec

10.8% NC / 3.9% DEGDN / 35.1% NIBTN / 35.2% AP / 15% LMH-2 (18)

Isp	T_c	Density
301 sec	3580°K	1.27 g/cc

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

11.4% NC / 23% TMETN / 22% Plasticizer / 27% AP / 3.2% Be / 13.5% LMH-2 (amorphous) (8)

Isp	T_c	Density
304 sec	3453°K	1.36 g/cc

63.5% Double Base Binder* / 17% AP / 19.5% LMH-2 (25)

Isp	T_c	Density
311 sec	3345°K	1.37 g/cc

*29% NC / 62% NG / 5% TA / 2% NDPA / 2% Res.

25% Binder (P-BEP/TVOPA :: 1/1) / 50% BTU / 20% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
297 sec	4255°K	1.828 g/cc	5940 ft/sec	366 sec

25% Binder (P-BEP/TMETN :: 1/1) / 60% BTU / 10% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
299 sec	4340°K	1.766 g/cc	5981 ft/sec	369 sec

70% P-BEP / 25% AP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
279 sec	3409°K	1.742 g/cc	5568 ft/sec	344 sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

NITRONIUM PERCHLORATE

20% PE / 65% NP / 15% Al (25)

Isp	T_c	Density	C*	Vac Isp
281 sec	3870°K	1.772 g/cc	5526 ft/sec	355 sec

20% PE / 62.5% NP / 17.5% LMH-1 (25)

Isp	T_c	Density	C*	Vac Isp
292 sec	3527°K	1.616 g/cc	5781 ft/sec	361 sec

48% TMETN / 2.3% PMMA / 29.6% NP (5% coat) / 1.1% Be / 19% Beane (8)

Isp	T_c	Density
317 sec	5388°K	1.27 g/cc

33% P-BEP / 43% NP / 24% LMH-2 (Density 0 ") (25)

Isp	T_c	Density
352 sec	3667°K	1.49 g/cc

35% P-BEP / 40% BTU / 20% NP / 5% Boron (25)

Isp	T_c	Density	C*	Vac Isp
300 sec	4408°K	1.807 g/cc	5951 ft/sec	374 sec

28.7% P-BEP / 14.4% NP / 11.7% Li / 45.2% BTU (25)

Isp	T_c	Density
308 sec	4761°K	1.40 g/cc

75% NP (5% coat) / 25% POLYU (25)

Isp	T_c	C*
270 sec	3518°K	5182 ft/sec

NOTE: All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

HAP

20% PE / 65% HAP / 15% Al (25)

Isp	T_c	Density	C*	Vac Isp
263 sec	2930°K	1.699 g/cc	5237 ft/sec	321 sec

20% PE / 55% HAP / 25% IMH-1 (25)

Isp	T_c	Density	Vac Isp
272 sec	2423°K	1.53 g/cc	343 sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio c. 40:1.

INFO 635

15% NC / 30% TMETN / 1% AN / 44% INFO 635 / 10% Al (25)

Isp	T_c	Density	C*
279 sec	3640°K	1.79 g/cc	5510 ft/sec

8% NC / 24% TEGDN / 50% INFO 635 / 18% LMH-1

Isp	T_c	Density	C*	Vac Isp
280 sec	3156°K	1.62 g/cc	5545 ft/sec	410 sec

NOTE:
All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.
All vacuum specific impulse values are at 1000 psia chamber pressure and ar expansion ratio of 40:1.

XII. ABBREVIATIONS AND CODE NAMES

for

SECTIONS X AND XI

ABBREVIATIONS AND CODE NAMES

Symbol	Name
Al	Aluminum
AN	Adiponitrile
AP	Ammonium perchlorate
Be	Beryllium
Beane	Beryllium hydride
BTU	Bis [Tris (Difluoramino) methyl] urea
DEGDN	Diethyleneglycoldinitrate
EC	Ethyl centralite
HAP	Hydroxylammonium perchlorate
INFO 635	[2-Tris (Difluoramino) methoxy] ethylammonium perchlorate
Li	Lithium
LMH-1	Aluminum hydride
LMH-2	Beryllium hydride
NC	Nitrocellulose
NDPA	2-Nitrodiphenylamine
NG	Nitroglycerin
NIBTN	Nitroisobutane trinitrate
NP	Nitronium perchlorate
P-BEP	Poly [1, 2-bis (difluoramino)] -2, 3-epoxy propane
PE	Polyethylene
PMMA	Polymethylmethacrylate
PNC	Polynitrocellulose
POLYU	Polyurethane
Res	Resorcinol
TA	Triacetin
TAZ	Triaminoguanadiniumazide
TDI	Toluene diisocyanate
TEGDN	Triethyleneglycol dinitrate
THA	TAZ · $N_2H_5N_3$
TMETN	Trimethylolethane trinitrate
TVOPA	Tris [bis (difluoramino) vinoxy] propane

XIII. SOLID PROPELLANT DATA SOURCE LIST

SOLID PROPELLANT DATA SOURCE LIST

1. 1103A Computer Program Data File
2. National Bureau of Standards
3. Pennsalt Chemicals Corporation
4. Esso Research and Engineering Company
5. Callery Chemical Company
6. American Cyanamid Company
7. Dow Chemical Company
8. Atlantic Research Corporation
9. Aerojet-General Corporation
10. E. I. du Pont de Nemours & Company
11. Minnesota Mining and Manufacturing Company
12. Ethyl Corporation
13. Union Carbide Chemical Company
14. Chemical Engineering Handbook
15. Handbook of Chemistry and Physics
16. JANAF Compilation
17. United Technology Corporation
18. Lockheed Propulsion Company
19. Rocketdyne
20. Navy Propellant Plant
21. National Research Corporation
22. Thiokol Chemical Corporation
23. AFRPL (RPCL) - calculated
24. United Aircraft Corporation
25. AFRPL Computer Program

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Dept. of the Air Force AFSC, RTD Air Force Rocket Propulsion Laboratory, Edwards, Calif.	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP 4

3. REPORT TITLE

Propellant Handbook (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

von Doehren, Paul J., Lt, USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1966	135	

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFRPL-TR-66-4
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. AVAILABILITY/LIMITATION NOTICES In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL-(RPC).

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	See Block 1

13. ABSTRACT

(U) A compilation of data on both liquid and solid propellants is presented with emphasis on liquids. Physical properties of liquids include: boiling point, freezing point, density, heat of formation, vapor pressure, critical properties, heat of vaporization, viscosity and specific heat. A discussion of the preparation method, toxicity, sensitivity, compatibility and availability of liquid propellants is also given. Property data on solid propellant components consists of densities and heats of formation. The results of theoretical calculations on the performance of both liquids and solids is presented and includes, when available and applicable, the maximum specific impulse, characteristic exhaust velocity, chamber temperature, mixture ratio, bulk density, maximum density impulse and mixture ratio, vacuum specific impulse and area ratio.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rocket Chemical Propellants Propellants Handbook Liquid Propellants Solid Propellants						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.